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Patent and Trademark Office: U.S. DEPARTMENT OF COMMERCE

NEW UTILITY PATENT APPLICATION TRANSMITTAL

(only for new nonprovisional applications under 37 CFR 1.53(b))

Attorney Docket Number	2962
First Named Inventor	Damodar Das Periwal
Total Pages in this Submission	121
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APPLICATION ELEMENTS

1. ☑ Fee Transmittal Form (in duplicate)
   - ☑ Check Enclosed
2. ☑ Specification
   (preferred arrangement set forth below)
   - Descriptive Title of the Invention
   - Cross Reference(s) to Related Case(s)
   - Statement Regarding Fed sponsored R & D
   - Background of the Invention
   - Brief Summary of the Invention
   - Brief Description of the Drawing(s)
   - Detailed Description
   - Claim or Claims
   - Abstract of the Disclosure
3. ☑ Drawing(s) *(when necessary per 35 USC 113)*
4. Oath or Declaration
   - a. ☑ New Declaration
     - ☑ Executed
   - b. ☐ Copy from a prior application (37 CFR 1 63(d))
     (for continuation/divisional with Box 17 completed)
     - i. ☐ DELETION OF INVENTOR(S)
       Signed statement attached deleting inventor(s) named in the prior application, see 37 CFR 1 63(d)(2) and 1.33(b).
5. ☐ Incorporation by Reference *(useable if Box 4b is checked)*. The entire disclosure of the prior application, from which a copy of the oath or declaration is supplied under Box 4b, is considered as being part of the disclosure of the accompanying application and is hereby incorporated by reference therein.

ACCOMPANYING APPLICATION PARTS

6. ☑ Assignment & PTO-1595
7. ☐ Certified Copy of Priority Document(s)
   (if foreign priority is claimed)
8. ☐ Information Disclosure Statement & PTO-1449
   - ☐ Copies of IDS Citation(s)
9. ☐ Preliminary Amendment
10. Small Entity Statement
    - ☑ New Statement enclosed
    - ☐ Statement filed in prior application. Status still proper and desired
11. ☑ Return Postcard
12. ☐ ____
13. ☐ ____
14. ☐ ____
15. ☐ ____
16. ☐ ____

ADDRESS TO:
Assistant Commissioner for Patents
Box Patent Application
Washington, D.C. 20231

17. **If a CONTINUING APPLICATION,** *check appropriate box and supply the requisite information below and in a preliminary amendment.*
☐ Continuation ☐ Divisional ☐ Continuation-in-part (CIP) of prior application No: ___/_______
Prior application information: Examiner: ____________ *Group/Art Unit:* ________

18. CORRESPONDENCE ADDRESS

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0002/PTO(modified) U.S. Department of Commerce
Rev. 10/95 Patent and Trademark Office

FEE TRANSMITTAL

TOTAL AMOUNT OF PAYMENT

Subtotal (1) + Subtotal (2) + Subtotal (3) = **($)885.00**

Complete if Known	
Application Number	
Filing Date	March 23, 1998
First Named Inventor	Damodar Das Periwal
Group Art Unit	Unknown
Examiner Name	Unknown
Attorney Docket Number	2962

METHOD OF PAYMENT

1. The Commissioner is hereby authorized to:

[ ] Charge the indicated fees to the below mentioned deposit account.

[X] Charge any additional fee required under 37 CFR 1.16 and 1.17 or credit any over payments to the below mentioned deposit account. †

[ ] Charge the Issue Fee set in 37 CFR 1.18 at the Mailing of the Notice of Allowance, 37 CFR 1 311(b) to the below mentioned deposit account

Deposit Account Number: 19-2555
Deposit Account Name: FENWICK & WEST LLP

A Duplicate Copy of this authorization is attached

2. [X] Payment Enclosed:
[X] Check [ ] Other

FEE CALCULATION (fees effective 10/01/97)

1. FILING FEE

Large Entity Fee Code/Fee	Small Entity Fee Code/Fee	Fee Description	Fee Due
101/$790	201/$395	Utility Filing	395.
106/$330	206/$165	Design Filing	
108/$790	208/$395	Reissue Filing	
114/$150	214/$75	Provisional Filing	

SUBTOTAL (1) ($)395.00

2. CLAIMS

Large Entity Fee Code/Fee	Small Entity Fee Code/Fee	Fee Description
103/$22	203/$11	Claims in excess of 20
102/$82	202/$41	Independent claims in excess of 3
104/$270	204/$135	Multiple dependent claim
109/$82	209/$41	Reissue independent claims over original patent
110/$22	210/$11	Reissue claims in excess of 20 and over original patent

For	(Col. 1) No. of Existing Claims		(Col 2) Highest No. Previously Paid For		(Col. 3) Extra**		Fee		Fee Due
TOTAL	46	minus*	20 or	=	26	x	11	=	286.
INDEP	7	minus*	3 or	=	4	x	41	=	164.
[ ] First presentation of multiple dependent claim								=	

* Subtract the greater number of Col. 2

** If the difference between Col 1 and Col 2 is less than zero, then enter "0" in Col. 3

SUBTOTAL (2) ($)450.00

FEE CALCULATION (continued)

3. ADDITIONAL FEES

Large Entity Fee Code/Fee	Small Entity Fee Code/Fee	Fee Description	Fee Due
105/$130	205/$65	Surcharge - late filing fee or oath	
127/$50	227/$25	Surcharge-late provisional filing fee or cover sheet	
147/$2,520	147/$2,520	For filing a request for reexamination	
115/$110	215/$55	Extension for response within first month†	
116/$400	216/$200	Extension for response within second month†	
117/$950	217/$475	Extension for response within third month†	
118/$1,510	218/$755	Extension for response within fourth month†	
128/$2,060	228/$1,030	Extension for response within fifth month†	
119/$310	219/$155	Notice of Appeal	
141/$1,320	241/$660	Petition to revive unintentionally abandoned application	
142/$1,320	242/$660	Utility Issue Fee (Or Reissue)	
143/$450	243/$225	Design Issue Fee	
122/$130	122/$130	Petitions to the Commissioner	
123/$50	123/$50	Petitions related to provisional applications	
126/$240	126/$240	Submission of Information Disclosure Statement	
581/$40	581/$40	Recording each patent assignment per property (times number of properties)	40.
146/$790	246/$395	Filing a submission after final rejection (37 CFR 1 129(a))	
149/$790	249/$395	For each additional invention to be examined (37 CFR 1 129(b))	
		Other fee (*specify*)	
		Other fee (*specify*)	

SUBTOTAL (3) ($)40.00

SUBMITTED BY		Complete (if applicable)	
Typed or Printed Name	Greg T. Sueoka	Reg. Number	33,800
Signature	Greg Sueoka	Date	March 23, 1998

† *Request for Extension of Time per 37 CFR 1 136 (a)(3) made hereby*

Rev. 03/23/98

A SYSTEM AND METHOD FOR EXCHANGING DATA AND COMMANDS BETWEEN AN OBJECT ORIENTED SYSTEM AND A RELATIONAL SYSTEM

Inventor: Damodar D. Periwal

BACKGROUND OF THE INVENTION

1. Field of the Invention.

The present invention relates generally to systems and methods for transferring data and commands between computing systems. In particular, the present invention relates to a system and a method for exchanging data and commands between an object oriented system and a relational system.

2. Description of the Background Art.

With the development and proliferation of computers of increasing performance capability, a number of different languages and programming paradigms have been developed. These languages and programming paradigms are used in conjunction with data that can be stored persistently in a variety of different ways. For example, options for persistent storage include relational databases, file systems and object-oriented databases.

Most data has been stored in a relational format such as in tables of a relational database. The data is manipulated and maintained by a relational database management system (RDBMS). One particularly attractive attribute of such relational systems is that RDBMSs are able to persistently store data. Relational systems are

persistent in the sense that the data is stored in a stable storage environment such that the data is accessible even after the application that created the original data stops executing. Furthermore, there are a number of applications and tools available for the manipulation and maintenance of such data in relational databases. Since relational databases have been in existence for many years, the use and proliferation of such applications and tools are widespread, and sophistication and capabilities of the tools are great.

However, a new programming paradigm that has become more widespread in recent years is object-oriented programming (OOP). In fact, OOP is becoming the dominant programming paradigm with the development and widespread use of new programming languages such as JAVA and C++. In OOP, a class is used to encapsulate the structure and behavior of objects. Thus, the objects contain both the data and the functionality for manipulation of the data.

It is very natural and desirable for application developers to represent the business objects in an object-oriented language like Java and at the same time use RDBMS for the persistence storage of those objects.

One problem existing in the art is that there are no systems and methods to bridge the gap between the programming paradigm used for object-oriented systems and the programming paradigm used for relational systems. There are also no systems and methods for bridging the gap between the languages used for object-oriented systems such as Java and the languages used in relational systems such as SQL. Furthermore, there is no easy method for specifying the mapping between such object-

oriented systems and relational systems. Thus, to perform translation between these systems has required hand coding of the mapping between object-oriented systems and relational systems, and hand coding is tedious, time-consuming, error-prone and tends to be non-uniform. Therefore, there is a need for systems and method for automatically translating and exchanging data between object-oriented systems and relational systems.

The prior art has attempted to solve the problem with graphical user interfaces that define mappings and by producing proprietary platform specific code that will translate between object-oriented systems and relational systems. However, such prior art systems have the following shortcomings. First, they are not always able to create a relational schema given an object model. Second, they are not always able to produce an object model given a relational schema. Third, they do not provide a uniform method for specifying directed options for object graph specification for different operations. Fourth, the prior art is not able to handle large sets of queried objects by streaming them between different tiers of applications. Thus, they are subject to memory bandwidth and response-time performance problems. Finally, such existing systems are coded for operation with a particular RDBMS. Thus, they are not interoperable among different relational back ends.

In object-oriented systems, when a new object is created it is typically assigned an identification number that can identify it uniquely among other objects of the same type. If objects are stored persistently in a database, the identification number assigned to a newly created object in memory should be unique with respect to even the already

stored objects in the database. So there is a need for a system and method having the ability to always provide a unique number. The existing art has attempted to solve the problem of providing unique identification numbers by providing the notion of a unique row-id in the RDBMS, thereby assigning a newly inserted row a unique number. However, the prior art approach has a number of disadvantages. First, the unique id is not known to the program until the object is inserted in the database. So if the programmer has to create related objects which need to know the unique ids for their initialization, the current scheme would require an insert operation and then a query operation to get the RDBMS assigned unique id. This is inefficient and cumbersome. Second, not all RDBMSs have the feature of unique row-ids, thus, such systems in the prior art cannot generate unique ids. Third, each RDBMS specifies its own unique way of defining and retrieving these row ids. So the application programmer cannot use a consistent and portable way of defining, using and referring to the unique ids.

Therefore, because of the advantages offered by OOP and the persistence of data offered by relational systems there is a need for a system that can easily be configured and that can reliably and automatically transfer data between such relational systems and object-oriented systems.

SUMMARY OF THE INVENTION

The present invention overcomes the deficiencies and limitations of the prior art with a system and methods for exchanging data and commands between an object oriented system and a relational system. In particular, the system of the present

invention comprises an Object-Relational Mapping (ORM) grammar, an ORM specification, Object Class Definitions, a relational database, an operating system, a Database Exchange Unit including an OR mapping unit, a schema generator, a schema reverse engineering unit and applications. The ORM specification is based on the ORM grammar and includes information for defining the mapping between the object-oriented system and the relational system. The Object Class Definitions define the object-oriented system, and the relational database defines the relational system. The Database Exchange Unit executes in accordance with the ORM specification, and is the programs/routines that operate to translate data from the object model to the relational model, and vice versa. The schema reverse engineering unit creates Object Class Definitions and an ORM specification from an ORM template specification and database schema. The schema generator generates the RDBMS schema from Object Class Definitions and the ORM specification. The system and method of the present invention are particularly advantageous due to an innovative grammar used to define the mapping between an object-oriented system and a relational system. The specification of mapping information using this innovative grammar allows the mapping information to be stored conveniently and easily in an operating system file and also as part of the relational database. The present invention also provides an application programming interface (API) that automates the tedious object-oriented program translation code between the relational system and the object oriented system. Furthermore, the system and methods of the present invention include units to provide for the automatic, sequenced number generation for new objects. This is advantageous

because it provides user flexibility in naming object identifiers for persistent storage in the database while ensuring that the object identifiers are unique.

The present invention further comprises a number of methods including: a method for generating a ORM Data Structure; a method for generating a mapping unit; a method for generating a schema from an object model and an object-relational mapping specification; a method for generating Object Class Definitions and an ORM specification from an ORM template specification and database schema; and a method for object streaming.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a block diagram of a first and preferred embodiment for a system constructed according to a preferred embodiment of the present invention for object-relational mapping.

Figure 2 is a block diagram of a first and preferred embodiment of a memory used in the system of Figure 1, and including the present invention.

Figure 3 is a block diagram of a second embodiment of the system of the present invention illustrating the present invention implemented as modules.

Figure 4 is a block diagram of a first embodiment of a Database Exchange Unit of Figure 2 as routines stored in the memory of the system.

Figure 5 is a block diagram of a second embodiment of the Database Exchange Unit constructed as modules.

Figure 6 is a block diagram of a first embodiment of a schema generator of Figure 2 as routines stored in the memory of the system.

Figure 7 is a block diagram of a second embodiment of the schema generator constructed as modules.

Figure 8 is a block diagram of a first embodiment of a schema reverse engineering unit of Figure 2 as routines stored in the memory of the system.

Figure 9 is a block diagram of a second embodiment of the schema reverse engineering unit constructed as modules.

Figure 10 is a flowchart of the preferred process for generating an ORM Data Structure according to the present invention from an ORMID or ORM file;

Figure 11 is a flowchart of the preferred process for generating ORM Data Structures according to the present invention using an ORM specification;

Figure 12 is a flowchart of the preferred process for generating relational schema from an ORM specification and Object Class Definitions.

Figure 13 is a flowchart of the preferred process for generating an ORM specification and Object Class Definitions from a database schema.

Figures 14A and 14B are a flowchart of the preferred process for responding to an object call using a mapping unit generated from an ORM specification.

Figure 15 is a flowchart of the preferred process for object streaming.

Figure 16 is a flowchart of the preferred process for generating foreign key entries and associating them according to a plan data structure set up as per directed query options.

Figure 17 is the specification of an exemplary ORM grammar used in the present invention.

Figure 18 is a textual representation of an exemplary ORM specification;

Figure 19 is a graphical representation of the exemplary ORM specification of Figure 17 showing the mappings between the object model and the relational model that will be performed by a database exchange using the exemplary ORM specification.

Figures 20A-20D are block diagrams of architectural configurations of the present invention in different tiers (parts) of applications using different relational database management systems.

Figures 21A-21B are graphic block diagrams of architectural configurations without and with the present invention.

Figures 22A and 22B are flowcharts of the preferred process for generating Named Sequence Generators and using them to produce persistent object identification numbers.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to Figure 1, a block diagram of a preferred embodiment of an object-relational mapping system 100 constructed in accordance with the present invention is shown. The object-relational mapping system 100 preferably comprises a central processing unit or processor 102 that connects with a memory 104, an input device 106, an output or display device 108, a data storage device 110, and a network

interface 112. The processor 102, memory 104, input device 106, output device 108, storage device 110, and network interface 112 are preferably coupled in a von Neuman architecture via a bus 114 such as a personal or mini computer. The processor 102 is preferably a microprocessor such as a Sun Sparc, PowerPC or an Intel Pentium; the output device 108 is preferably a video monitor; and the input device 106 is preferably a keyboard and mouse-type controller. The memory 104 is preferably random access memory (RAM) and read-only memory (ROM). The processor 102 is also coupled to the network interface 112 in a conventional manner for connection to a network via line 116 and other computers such as via a local area network, wide area network or the Internet. In an exemplary embodiment, the object-relational mapping system 100 operates on an IBM-type personal computer. Those skilled in the art will realize that the object-relational mapping system 100 could also be implemented as any one of a variety of other computers such as those made by Apple, Sun, Digital Equipment Corporation or IBM.

The object-relational mapping system 100 of the present invention provides for the automatic and systematic exchange of data and commands between an object-oriented system and a relational system. The processor 102, under the guidance of instructions received from the memory 104 and from the user through the input device 106, provides signals for the exchange of data and commands between an object-oriented system and a relational system. The memory 104 preferably includes an ORM Grammar 200, an ORM Specification 202, Object Class Definitions 204, a relational database management system (RDBMS) 206, an operating system 208, a Database

Exchange Unit 210, a schema generator 212, RDBMS tables and ORMMetadata Tables 214, applications 216, a GUI or text editor 218, a schema reverse-engineering unit 220, an ORM template specification 222, a Metadata ORM specification 224, and Named Sequence Generators 226. The operation interaction of the above modules of the present invention provides for the automatic, systematic exchange of data between an object- oriented system and a relational system. In particular, the present invention with the above modules allows for: 1) the generation of modules (ORM Data Structure) for translation of data from an objectoriented system to a relational system based on an ORM specification; 2) the generation of an ORM specification and an Object Class Definitions from a database schema; 3) the generation of a relational schema from an ORM Specification and Object Class Definitions; and 4) the transfer of data between the object-oriented system and the relational system. Those skilled in the art will realize that various equivalent combinations of devices can achieve the same results when used in accordance with the present invention. For example, while the memory blocks 200, 202, 204, 206, 208, 210, 212, 214, 216, 218, 220, 222, 224 and 226 are shown as separate, units and coupled to each other and other components by the bus 114, they can easily comprise different regions of a contiguous space in memory. While the memory blocks 200, 202, 204, 206, 208, 210, 212, 214, 216, 218, 220, 222, 224 and 226 will now be described as routines or modules, and therefore primarily defined by their functionality, those skilled in the art will recognize that the particular modules or portions could be implemented in hardware as an alternate embodiment.

The system and methods of the present invention are particularly advantageous because of the use of an innovative ORM Grammar 200 to define the mapping between an object-oriented system and a relational system. Such an exemplary grammar is shown in Figure 17. Furthermore, Appendix A provides more detail on the ORM Grammar 200 including the syntax, an explanation and an example. The ORM Grammar 200 the rules for textually describing an Object-Relational Mapping (ORM) in a declarative way. The specification of mapping information using this innovative Grammar 200 allows the mapping information to be stored conveniently and easily in an operating system file and also as part of the relational database, as will be discussed in more detail below with reference to Figure 10. This ORM Grammar 200 is shown in detail in Figure 17. While the ORM Grammar 200 is shown as being stored in memory, the ORM Grammar 200 may in alternate embodiments be used to generate and interpret an ORM Specification 202 without being stored in memory 104. The ORM Grammar 200 of the present invention is particularly advantageous because it provides an extensible textual system in which it is very easy for the user to add new constructs for specifying mappings between the relational model and the object model. For example, one can easily add new rules to define mappings other that those provided in Figure 17. Such examples for extending the ORM Grammar 200, descriptions of their functionality and the API are provided in Appendix D.

Referring again to Figure 2, the memory 104 is shown as including an ORM Specification 202. An ORM Specification 202 is a textual specification of an instance of object-relational mapping information based on the ORM Grammar 200. In other

words, the ORM Specification 202 defines how data is mapped from the object-oriented system to the relational system and vice versa. The present invention is particularly advantageous because of the use and structure of the ORM Specification 202. More specifically, the ORM Specification 202 is preferably a text file or ORM file, and specifies the mapping using the ORM Grammar 200 discussed above and shown in Figure 17. In the preferred embodiment, the ORM Specification 202 can be indexed or referred to by using an ORMID. Since the ORM Specification 202 is described textually, it can be stored easily in memory 104, a storage device 110 or even as part of a relational database. Furthermore, because the ORM Specification 202 is described textually there is no special software required to create, view and edit the ORM Specification 202. Any one of a variety of text editor or graphical user interfaces can be used to create, modify and review ORM Specifications 202. One such exemplary ORM Specification 202 is shown in Figure 18.

The memory 104 also includes Object Class Definitions 204 that define an object model. Object Class Definitions 204 describe an object model in an object-oriented language such as Java. The Object Class Definitions 204 describe the object model in a conventional manner such that objects are instances of classes. The Object Class Definitions 204 essentially define the object-oriented system and formatting for data that is transferred from or to the object-oriented system. One such exemplary set of Object Class Definitions 204 is graphically depicted in Figure 19, and the concept typical of such object models are described for the particular example in Appendix B.

Also included in the memory 104 is a relational database management system (RDBMS) 206. The RDBMS 206 may be any one of a conventional type such as Oracle, Sybase, Informix, Microsoft SQL server, and IBM DB2. The RDBMS 206 preferably includes routines and modules for storing, retrieving and editing data maintained in a relational system such as may be present on the storage device 110 or distributed over the network and accessible via the network interface 112.

The memory 104 also includes one or more operating systems 208. The operating system is preferably a conventional personal computer operating system such as UNIX, or DOS and Windows sold by Microsoft Corporation. Alternatively, the present invention could use other conventional operating systems such as OS/2 or System 8.0 for the Macintosh by Apple Computer.

A Database Exchange Unit 210 is also included in the memory 104. The Database Exchange Unit 210 is the routine or module that controls the processor 102 to perform the actual exchange of data from the relational system to the object-oriented system. At the highest level, it includes programs and routines that operate to translate data from the object model to the relational model and vice versa. The Database Exchange Unit 210 is initialized using an ORM Data Structure Creation Unit 302 as will be described in more detail below, and once initialized, operates independently using the OR Mapping Unit 304 to perform data and command translation.

The Schema Generator 212 is also stored in memory 104. The Schema Generator 212 is a tool or routines for controlling the processor 102 to generate the relational database schema (table definitions, constraint definitions) as well as metadata

information corresponding to the Object Class Definitions 204 and the ORM Data Structures 308 during initialization. After the relational database schema have been created, they are stored in memory 104 or the RDBMS 206 and used by OR Mapping Unit 304 to map object calls to database requests. The Schema Generator 212 (e. g., JDXSchema in Java) is preferably invoked with the command:

java JDXSchema [-metaCreate | -metaInit | -init] <ORMFile>

This Schema Generator 212 takes the name of the file (e. g., abc.jdx) containing the Object-Relational Mapping information as input, and generates three script files containing the SQL DDL statements for creating the required tables and their primary keys (abc.jdx.create); foreign key constraints (abc.jdx.alter); and dropping those constraints and tables (abc.jdx.drop). Before using the database 206 for Object-Relational Mapping (for the very first time), the flag -metaCreate is used. This causes the ORMMetadata Tables 214 to be created in the database 206. These ORMMetadata Tables 214 are subsequently used to store the Object-Relational Mapping information. By using the flag -metainit one can store just the Object-Relational Mapping information (metadata) in the database 206 corresponding to a given ORMID. This is useful when the database tables for user objects do not need to be (re-) created. By using the flag -init, the above scripts are automatically executed against the database 206 such that the user can start creating and using persistent user objects against the database in Java programs. The flag -init also stores the Object-Relational Mapping information (metadata) in the database 206 corresponding to the given ORMID in <ORMFile>. Only one of the three options (metaCreate, metaInit, init) may be specified.

The memory 104 also includes RDBMS Tables and ORMMetadata Tables 214. The RDBMS Tables 214 basically define the relational model just as the Object Class Definitions 204 define the object model. In other words, the RDBMS Tables 214 set forth the organization and structure of the data in the relational model in addition to describing certain functionality provided by the relational model. The RDBMS Tables 214 hold persistent data for the objects which are instances of the Object Class Definitions 204.

The present invention also stores multiple ORM Specifications 202 in the ORMMetadata Tables 214 that are part of the database 206. The ORMMetadata Tables 214 hold persistent data for the ORM Specification 202 and Named Sequence Generator 226. Most modern RDBMSs support a data type of LONGVARCHAR (e.g., 'text' in Sybase RDBMS) which can accommodate large textual data. Having a database table ORMMetadata 214 with the following structure provides a convenient way to store the Object-Relational Mapping information. For example, the command

```
CREATE TABLE ORMMetadata (ORMId varchar(80), MetaInfo
        LONGVARCHAR, MetaFileName varchar(80) CONSTRAINT
        PK_ORMMetadata PRIMARY KEY (ORMId));
```

can be used to store the ORM Specification 202 in the database 206, where the ORMId (defined below with reference to Figure 10) identifies the specification uniquely. The text of the ORM File goes into the MetaInfo field, and the MetaFileName field is initialized with the ORM File name for recording purpose. Even if the RDBMS 206 does not support a LONGVARCHAR style field, it is easy to store the MetaInfo text in

multiple rows of a separate table with a varchar(255) field and an ORMId field. The ORMId field has the same value for all the records holding chunks of MetaInfo for a particular ORMId. A time stamp field is preferably added to the ORMMetadata Tables 214 to keep track of when the particular mapping information was created. A version field that identifies the version of the grammar describing the Object-Relational Mapping information stored in MetaInfo field is also included in the ORMMetadata Tables 214. The version information is employed to correct the interpreter for the specification because the ORM Grammar 200 of the specification may change to accommodate new functionality.

Thus, the ORMMetadata Table 214 provides a very convenient facility to store multiple Object-Relational Mapping information, each identifiable uniquely through ORMIds. It also provides an elegant way of partitioning the object view of the underlying relational data. The ORMMetadata Tables 214 also include a table for storing sequence number information as will be described below with reference to the Named Sequence Generators 226.

The memory 104 also includes applications 216 and a text editor or graphical user interface 218. The applications 216 may be any one of a conventional type written in object-oriented languages such as Java. The applications 216 are routines or modules that allow the user to access data in the system 100. Also included in memory 104 is a conventional text editor or graphical user interface 218. The text editor or graphical user interface 218 may be any one of a number of conventional editing interfaces. As noted above, since the ORM Specification 202 is a text file, any type of text editors or

graphical user interfaces 218 may be included in the system 100, and thereby be used to change the ORM Specification 202 and thus how data and commands are exchanged between the relational system and the object-oriented system.

The memory 104 also includes a Schema Reverse Engineering Unit 220. The Schema Reverse Engineering Unit 220 is a routine or tool for creating Object Class Definitions 204 and ORM Specification 202 using a database schema (table definitions, constraint definitions) for a set of tables. The Schema Reverse Engineering Unit 220 provides the user, given a relational model, with the ability to generate the ORM Specification 202 for translating between the given relational model and an object-oriented model. The Schema Reverse Engineering Unit 220 also generates or defines the object-oriented model by creating the Object Class Definitions 204. The operation of the tools forming the Schema Reverse Engineering Unit 220 will be described in more detail below with reference to Figure 13.

Also included in the memory 104 is an ORM Template Specification 222. The ORM Template Specification 222 is a module that is used in conjunction with the Schema Reverse Engineering Unit 220. The ORM Template Specification 222 provides data that along with information about the relational model is used by the Schema Reverse Engineering Unit 220 to produce the Object Class Definitions 204 and the ORM Specification 202. The ORM Template Specification 222 is a simplified ORM Specification 202 including the names of the tables to be considered for generating Object Class Definitions 204. The metadata information about named tables in the RDBMS 206 is used to create Object Class Definitions 204.

The memory 104 further includes a Metadata ORM Specification 224. The Metadata ORM Specification 224 is a specification like the ORM Specification 202 that can be used to generate data structures for the object relational mapping. In particular, the Metadata ORM Specification 224 is preferably a predefined ORM Specification describing the object-relational mapping between metadata objects and ORMMetadata Tables 214 which store information about ORM Specification 202 and Named Sequence Generators 226.

Finally, the memory 104 includes Named Sequence Generators 226. Named Sequence Generators 226 are routines or modules that generate persistently unique sequence numbers. These unique sequence numbers are used in turn by the applications 216 to store unique objects in a database 206. Since the numbers are persistently unique, this ensures that old or existing objects will have different identification numbers. In the present invention, there is a unique declarative method for specifying named sequences, and the Named Sequence Generators 226 manage and control the use and creation of sequence numbers to ensure that there are no conflicts with existing sequence or identification number for objects, even among different applications. The present invention is advantageous because like the Grammar 200, the Named Sequence Generators 226 provide a declarative way of defining named sequences that can be used to generate persistently unique sequence numbers in an efficient way. These sequence numbers, among other things, can be used to assign unique ids to different objects. The Named Sequence Generators 226 of the present invention are particularly advantageous for a number of reasons. First, the grammar

for specifying sequence generators is simple and intuitive. Second, the declarative way of specifying the sequences is a compatible and convenient way of defining sequences along with Object Relational Mapping information. Third, the way sequences are named by the Named Sequence Generators 226 is done in a manner convenient for application programmers because it uses meaningful names (e. g., imageIdSequences) for the sequence generators, and allows the creation of multiple sequence number domains (e. g., partIdSequences, customerIdSequences, etc.). Fourth, the Named Sequence Generators 226 allow the user to specify a starting value for a sequence generator. This is very advantageous because for already existing data with a home-grown way of generating sequence numbers, the new method may be employed with a starting value of 1 more than the maximum value in the current set of data; and from problem domain or business needs a starting value other than 1 may be more appropriate such as when a new company starts its invoice numbers from 1001 or when 4 billion starts are already identified and documented and a new application for creating entries for new starts may use a sequence generator with a starting value of 4 billion and 1. Finally, the declaration of a sequence is database independent, and the sequence generator implementation mechanism can work with any backend relational database.

Also included with the Named Sequence Generators 226 are routines, specifically, an API (getNextSequence) to get the next set of persistence sequence numbers. The feature of specifying an increment in the API call of getNextSequence enables an efficient generation of sequence numbers without requiring a database call

for every new sequence number. The calling application can safely assume that no other application would get the next sequence number in the range of the returned sequence number n to n+increment-1 (both inclusive). The method for servicing the API is described below in more detail with reference to Figure 22.

Referring now to Figure 3, the present invention is best shown as being the coupling element between a relational system and an object-oriented system. In normal operation, the Database Exchange Unit 210 controls the transfer of data and commands between an application 216 (object-oriented system) and the RDBMS 206 (relational system). The Database Exchange Unit 210 is coupled to receive and send data and commands to and from the application 216 using conventional object-oriented techniques, such as constructs provided by an OOP language such as Java. The Database Exchange Unit 210 formats and structures the data and commands into and from a format suitable for an object-oriented system. Similarly, the Database Exchange Unit 210 is coupled to the RDBMS 206 to receive and send data and commands to and from the RDBMS 206 in a format suitable for relational systems. More particularly, the Database Exchange Unit 210 generates queries, inserts, updates and deletions, to fetch or modify the data in the RDBMS 206 based on the object calls received from the application 216. The Database Exchange Unit 210 is also coupled to the Object Class Definitions 204 and the ORM Specification 202. The Database Exchange Unit 210 interacts with the Object Class Definitions 204 during both initialization and normal operation to perform the exchange of data and commands between the application 216 and the RDBMS 206. The Database Exchange Unit 210 is also coupled to the ORM

Specification 202, but only interacts with the ORM Specification 202 as will be described in more detail below with reference to Figures 5 and Figure 11.

Referring now to Figure 4, the Database Exchange Unit 210 is shown in more detail. The Database Exchange Unit 210 preferably comprises an Object Call Processing Unit 300, an ORM Data Structure Creation Unit 302, an OR, Mapping Unit 304, a Database Interface Unit 306, and an ORM Data Structures 308. Each unit 300, 302, 304, 306 and 308 is preferably a routine or module stored in a block of memory 104 for controlling the processor 102 to perform the operations as will be described below. The units 300, 302, 304, 306 and 308 are coupled by bus 114 as shown, and their operation, exchange of data and functionality will be described below with reference to Figure 5. Those skilled in the art will recognize that while the memory blocks are shown as separate 300, 302, 304, 306 and 308, and coupled to each other and other components by the bus 114, they can easily comprise different regions of a contiguous space in memory 104.

The operation of the Database Exchange Unit 210 and its components is best shown in Figure 5. Figure 5 is a block diagram of Database Exchange Unit 210 constructed as modules and showing the coupling utilized by their functionality. In Figure 5, the couplings used for the transfer of data for initialization and the creation of the ORM Data Structures308 are shown by dashed lines for ease of understanding. As noted above, the Database Exchange Unit 210 is delineated in Figure 5 by a dashed block and comprises an Object Call Processing Unit 300, an ORM Data Structure Creation Unit 302, an OR Mapping Unit 304, a Database Interface Unit 306, and an

ORM Data Structures 308. The Object Class Definitions 204 and the ORM Specification 202 are stored in another portion of memory as has been described above with reference to Figure 2.

The ORM Data Structures 308 are in-memory data structures built from the ORM Specification 202 and Object Class Definitions 204. The ORM Data Structures 308 are used in the translating of object calls to relational data and commands. More specifically, the ORM Data Structures 308 preferably include the following data structures to store various information about the object-relational mapping:

Data Structure	Description
ColumnInfo	Stores the relational column information - name, SQL type etc.
Tableinfo	Stores the tableName, the list of ColumnInfo corresponding to its columns etc.
AttribInfo	Stores the following information about a class attribute: name, type, ColumnInfo etc.
ComplexAttribInfo	In addition to AttribInfo information, it also stores the information about the referenced object (or collection), the referencing attributes, the containment of the referenced object etc.
ReferenceKeyInfo	Stores information about the primary and reference keys of a class.
ClassInfo	Stores the className, reference to Tableinfo, list of AttribInfo, list of ComplexAttribInfo, etc.
CollectionClasssInfo	In addition to ClassInfo information for its element class, it also stores the information about collection type, containment type and order by attributes, etc.
DatabaseInfo	Stores url, ORMId, list of ClassInfo, list of Tableinfo, list of database connections, etc.

The ORM Data Structure Creation Unit 302 is preferably coupled to the Object Class Definitions 204 and the ORM Specification 202 to receive the object model and the

mapping between the relational system and the object-oriented system, respectively. The ORM Data Structure Creation Unit 302 is also coupled to the Database Interface Unit 306 for accessing the RDBMS 206 to receive schema that describe how the relational system organizes data. Using this information, the ORM Data Structure Creation Unit 302 generates the ORM Data Structures 308. The ORM Data Structure Creation Unit 302 is preferably routines or tools to generate the ORM Data Structures 308 using an ORM Specification 202 (coming from either an ORM file or Metainfo in the ORMMetadata Tables 214) and Object Class Definitions 204. In one embodiment, the ORM Data Structure Creation Unit 302 parses the ORM Specification 202 as per the ORM Grammar 200 specified and builds the ORM Data Structures 308. Each construct of the ORM Grammar 200 is used to create the data structures. For example, each <CLASS-SPEC> creates an instance of ClassInfo. Each <COLLECTION-CLASS-SPEC> creates an instance of CollectionClassInfo. The reflection facility of the language may be used to create the instances of AttribInfo. <PRIMARY-KEY-SPEC> and <REFERENCE-KEY-SPEC> are used to create instances of ReferenceKeyInfo. <RELATIONSHIP-SPEC> is used to create the instances of <ComplexAttribInfo>. Once the internal data structures have been built using data from the ORM Specification 202, each class is fully understood in terms of its different components and how they can be stored and retrieved using the Object Class Definitions 204. Next, the ORM Data Structure Creation Unit 302 retrieves user objects of these classes and generates appropriate SQL statements to insert, update or delete various components of those objects. If objects need to be retrieved, the top-level objects are retrieved first (based on an optional search

condition) and then their complex attributes are initialized after fetching the appropriate referenced objects as per the mapping information.

The remaining portions of the Database Exchange Unit 210, in addition to the ORM Data Structures 308, are used for the actual transfer of data and commands from the object-oriented system to the relational system, and vice versa. The Object Call Processing Unit 300 is coupled by line 250 to the application 216 to receive object-oriented commands/calls and data from the application 216. The Object Call Processing Unit 300 is also coupled to the OR Mapping Unit 304. The Object Call Processing Unit 300 receives calls and begins the translation of the object calls so that they can be executed on the relational system. More particularly, the Object Call Processing Unit 300 intercepts Application Programming Interface (API) level calls for object manipulation (query, insert, update, delete etc.) and executes those using OR Mapping Unit 304. Furthermore, a set of exemplary API calls which the Object Call Processing Unit 300 is responsive to are shown in Appendix C.

The OR Mapping Unit 304 is coupled to the Object Class Definitions 204, the ORM Data Structures 308, the Database Interface Unit 306, in addition to the Object Call Processing Unit 300. The OR Mapping Unit 304 is preferably routines or tools for performing the object-relational mapping using the ORM Data Structures 308, user objects (from the Object Class Definitions 204) and relational data (from the Database Interface Unit 306). The operation of the OR Mapping Unit 304 is described in more detail below with reference to Figures 14A and 14B. It should be noted that the Database Interface Unit 306 is used by the OR Mapping Unit 304 to access data from the

relational database. The Schema Generator 212 may optionally use the Database Exchange Unit 210 to initialize the ORMMetadata Tables 214 with ORM Specification 202 and Named Sequence Generators 228.

Referring now to Figure 6, a block diagram of a first embodiment of the Schema Generator 212 is shown. For convenience and ease of understanding, like reference numerals have been used to reference like parts. Furthermore, while shown and described below as being included as part of the Schema Generator 212 in this embodiment, certain modules such as the ORM Data Structure Creation Unit 302, ORM Data Structures 308 and Database Interface Unit 306 could alternatively be part of the Database Exchange Unit 210 as described above, and omitted from the Schema Generator 212. In such an embodiment, the ORM Data Structure Creation Unit 302, ORM Data Structures 308 and Database Interface Unit 306 in the Database Exchange Unit 210 would be used by the Schema Generator 212.

The Schema Generator 212 preferably comprises the ORM Data Structure Creation Unit 302, the ORM Data Structures 308, the Database Interface Unit 306, a Relational Schema Statements Generation Unit 602, Script Files Containing Relational Schema Statements 604 and a Relational Schema Statements Application Unit 606. Each unit 302, 306, 308, 602, 604 and 606 is preferably a routine or file stored in a block of memory 104 for controlling the processor 102 to perform the operations as will be described below. The ORM Specification (an ORMFile) 202 may be used to create the database schema, and this is done by the Schema Generator 212. The tables in the schema are preferably used to hold the data for the class objects. The units 302, 306, 308,

602, 604 and 606 are coupled by bus 114 as shown, and their operation and functionality will be described below with reference to Figure 7.

Figure 7 is a block diagram of a second embodiment of the Schema Generator 212 constructed as modules. The operation of the Schema Generator 212 can best be understood by reference to the operation according to Figure 7. As shown in Figure 7, the ORM Data Structure Creation Unit 302 is coupled to the Object Class Definitions 204, the ORM Specification 202 and the Metadata ORM Specification 224. The Object Class Definitions 204, the ORM Specification 202 and the Metadata ORM Specification 224 are preferably stored in another portion of memory 104 as has been described above with reference to Figure 2. The ORM Data Structure Creation Unit 302 uses the Object Class Definitions 204 and either the ORM Specification 202 or the Metadata ORM Specification 224 to generate an ORM Data Structures 308 as has been described above with reference to Figure 5. The ORM Data Structures 308 created for Metadata ORM Specification 224 can be used to store ORM Specification 202 and Named Sequence Generators 226 as information in ORMMetadata Tables 214. The ORM Data Structures 308 has a format and content as described above. The ORM Data Structures 308 is coupled as an input to the Relational Schema Statements Generation Unit 602. The Relational Schema Statements Generation Unit 602 is a routine or tools to produce statements that will produce the relational schema in the RBDMS 206. Using the information about the schema for the relational system contained in the ORM Data Structures 308, the Relational Schema Statements Generation Unit 602 produces the Script Files Containing Relational Schema Statements 604. The operation of the

Relational Schema Statements Generation Unit 602 is described in more detail below with reference to Figure 12. The output of the Relational Schema Statements Generation Unit 602 is coupled to the input of the Relational Schema Statements Application Unit 606 to provide the Script Files Containing Relational Schema Statements 604 produced by the Relational Schema Statements Generation Unit 602. The Relational Schema Statements Application Unit 606 is also coupled to the Database Interface Unit 306 and applies the commands necessary to produce the schema in the database with the table names and definitions. More particularly, the Relational Schema Statements Application Unit 606 through the Database Interface Unit 306 issues the commands from Script Files Containing Relational Schema Statements 604 to the RDBMS 206.

Referring now to Figure 8, a block diagram of a first embodiment of the Schema Reverse Engineering Unit 220 is shown. As noted above, the Schema Reverse Engineering Unit 220 is a tool to create an ORM Specification 202 and Object Class Definitions 204 given a database schema. Again, for convenience and ease of understanding, like reference numerals have been used to reference like parts, and while shown and described below as being included as part of the Schema Reverse Engineering Unit 220 in this embodiment, certain modules such as the ORM Data Structures 308 and Database Interface Unit 306 could alternatively be part of the Database Exchange Unit 210 as described above. In such an alternate embodiment, the Schema Reverse Engineering Unit 220 uses the ORM Data Structures 308 and Database Interface Unit 306 in the Database Exchange Unit 210. The Schema Reverse Engineering Unit 220 preferably comprises the Database Interface Unit 306, the ORM Data

Structures 308, the Object Class Definitions Generation Unit 802, the ORM Specification Generation Unit 804, the Database Metadata Inquiry Unit 806 and the Reverse Engineering ORM Structure Creation Unit 808. These modules 306, 308, 802, 804, 806, 808 are preferably routines stored in memory 104 and coupled by bus 114.

Referring now to Figure 9, a block diagram of a second embodiment of the Schema Reverse Engineering Unit 220 is shown. The ORM Template Specification 222 is a simplified ORM Specification with the names of tables to be considered or used for generating Object Class Definitions 204 and is provided to the Reverse Engineering ORM Structure Creation Unit 808. The Reverse Engineering ORM Structure Creation Unit 808 is also coupled to the RDBMS 206 (not shown in Figure 9) by the Database Metadata Inquiry Unit 806 and the Database Interface Unit 306. The Database Metadata Inquiry Unit 806 accesses the RDBMS 206 using the Database Interface Unit 306 to retrieve metadata including the schema for the relational model and information about the object model. The Database Metadata Inquiry Unit 806 provides the metadata to the Reverse Engineering ORM Structure Creation Unit 808. The Reverse Engineering ORM Structure Creation Unit 808 receives the ORM Template Specification 222. The ORM template information contains the names of the tables to be used for generating Object Class Definitions 204. The Reverse Engineering ORM Structure Creation Unit 808 uses the basic ORM template information along with the metadata to produce ORM Data Structures 308. The ORM Data Structures 308 is in turn used by the Object Class Definitions Generation Unit 802 and the ORM Specification Generation Unit 804 to produce the Object Class Definitions 204 and the ORM Specification 202, respectively.

The operation of the components of the Reverse Engineering ORM Structure Creation Unit 808 is described in more detail with reference to Figure 13 below.

One advantage of the present invention is that the structure of the ORM Specification 202 provides a very convenient way of experimenting with an Object-Relational Mapping. Since the ORM Specification 202 is stored as a text file, and the Database Exchange Unit 210 can be easily generated from the ORM Specification 202, the user can continue to refine and use the ORM Specification 202 until the user is satisfied with the results of Object-Relational Mapping. Furthermore, after the user is satisfied with the ORM Specification 202, the present invention stores this information at a common place such that many other applications or instances of the same application running on different machines can utilize this information. More specifically, the present invention stores it in the ORMMetadata Tables 214 that are part of the database 206.

Referring now to Figure 10, a flow chart of the preferred process for generating ORM Data Structures 308 according to the present invention from an ORM Id or ORM Specification (ORM file) 202 is shown. Each ORM specification 202 for mapping object classes into relational data is uniquely identified in the present invention by an object-relational mapping identification name (ORMId). An ORMId defines a view of objects over a set of tables. There may be multiple such views (overlapping or non-overlapping) identified by different ORMIds on the same database. ORMIds help in partitioning the relational data into different object spaces. The application 216 just

needs to deal with only the relevant partition instead of worrying about all the tables and all the different classes defined using those tables. The ORMId is preferably part of the <DATABASE-URL> defined in Appendix B.

With the present invention, the user is able to indicate that a specific file should be used to determine the mapping between the object model and the relational model. The user must either specify a particular file by providing an ORM file or provide an identification to an existing ORM Specification 202 stored in the database 206. Otherwise a default ORM Id for a default ORM Specification 202 stored in the database 206 will be used. The process begins with step 1000 by determining whether an ORM file has been specified. If an ORM file has been specified, then the method proceeds to step 1002 where the process is set to use the ORM file specified. This is done by setting the variable ORMFileName to the specified file. After step 1002, the method proceeds to step 1004 where the method uses the ORM Specification 202 corresponding to the ORMFileName to create an ORM Data Structures 308. The operations performed by the system 100 in step 1004 will be provided in more detail below with reference to Figure 11. After step 1004, the process is complete and ends. On the other hand, if in step 1000, an ORM file was not specified, then the method continues to step 1006. In step 1006, the method determines whether an ORM identification (Id) has been specified. If an ORM Id has been specified, method continues in step 1008 and uses the given ORM Id to set the variable ORMID. If an ORM Id has not been specified, the method continues in step 1010, and uses a default ORM Id to set the variable ORMID. For example, the default ORM Id is the string "defaultORMId". After either step 1008 or

step 1010 the method proceeds to step 1012. In step 1012, for the variable ORMID, the method extracts Metainfo from the database table, ORMMetadata Tables 214, into a local file. Then in step 1014, the method sets the variable ORMFileName to the name of the local file created in step 1012. After step 1014, the method proceeds to step 1004 and creates the ORM Data Structures 308 as has been described above. As can be seen from steps 1000 to 1014, the method of the present invention is particularly advantageous because by providing the system 100 with an ORM file, or an ORM Id or just using the default ORM Id, the system 100 can generate the ORM Data Structures 308 which specifies the mapping between the relational model and the object-oriented model. This is particularly advantageous because it allows the translation between the object-oriented model and relational model to be stored in a persistent manner either within the database 206, on the network (not shown) and accessed via the network interface 112, or in any one of a number of storage devices 110 coupled to the system 100.

When an object-oriented application program 216 wants to use a particular Object-Relational Mapping specification, it just has to specify the corresponding ORMId. Then it is a matter of retrieving the MetaInfo into a temporary file and using the process described above with reference to Figure 10 to provide Object-Relational Mapping functionality. With some optional cleverness, a character stream may be realized over the MetaInfo field and the creation of a temporary file may be avoided. Even after permanently storing the Object-Relational Mapping information in the database 206, it may be possible to override that by specifying <ORMFile> clause in the <DATABASE-SPEC>. This gives a very innovative way of doing program

development and refinement. The old programs continue to work with the stored specification while the new development may be happening with the new specifications in local text files.

Referring now to Figure 11, a flow chart of the preferred process for generating the ORM Data Structures 308 according the present invention using an ORM Specification 202 and Object Class Definitions 204 is shown. This method corresponds to step 1004 of Figure 10, and includes the steps necessary to create instances of each of the ORM Data Structures 308. Each of these ORM Data Structures 308 has been defined above in the discussion of Figure 2. The method begins in step 1102 by creating an instance of DatabaseInfo. Next in step 1104, the method continues by creating an instance of TableInfo and ClassInfo for each class specification. Then the method continues by creating an instance of CollectionClassInfo for each collection specification. Then in step 1108, the method creates the instances of Attribinfo for each ClassInfo. Next in step 1110, the process uses any SQL map specification to override the default mappings between the columns and attributes. Then in step 1112, the method uses Primary-Key and Reference-Key specifications to create instances of ReferenceKeyinfo. The method continues in step 1114, by using the relationship specification to create instances of ComplexAttributeInfo. Then in step 1116 the system 100 retrieves Metadata from the database 206 to enhance TableInfo with instances of ColumnInfo. Next in step 1118, the method matches AttributeInfo with ColumnInfo. Then after step 1118, the method in step 1120 generates SQL statements for each class using the instances of TableInfo and ColumnInfo. Finally, in step 1122, the system 100 generates

insert and update statements in parameterized form after which the process ends.

Referring now to Figure 12, a flow chart of the preferred process for generating relational schema from an ORM Specification 202 and Object Class Definitions 204 is shown. As indicated Figure 12, the preferred process for generating relational schema includes many of the same process steps described above with reference to Figure 11 for the process of generating the ORM Data Structures 308. For convenience and ease of understanding, like reference numerals are used to indicate like steps including steps 1102 through 1114 which are preferably identical to the steps described above with reference to Figure 11. Thus, the preferred method for generating relational schema from the ORM Specification 202 and the Object Class Definitions 204 begins by performing steps 1102 through 1114. However, after step 1114, the method of Figure 12 continues in step 1202. In step 1202, the method adds ColumnInfo in TableInfo for each primitive and embedded attribute of each ClassInfo. Then in step 1204, the system 100 generates a create table statement and primary key constraint statement in a CREATE file for each TableInfo. Next in step 1206, the method generates unique key and referential key constraint statements in an ALTER file for each ClassInfo. Then in step 1208, the method generates alter table drop constraint statements and drop table statements in a DROP file for each ClassInfo. Finally in step 1210, the method executes the CREATE, ALTER and DROP files to modify the database 206.

Referring now to Figure 13, a flow chart of the preferred process for generating an ORM Specification 202 and Object Class Definitions 204 from a database schema is shown. The process for generating an ORM Specification 202 begins in step 1302 by

creating an instance of DatabaseInfo. The method continues in step 1304 by creating an instance of ClassInfo and TableInfo for each class in the ORM Template Specification 222. The method then proceeds to step 1306 where a metadata query and creation of ColumnInfo and AttributeInfo in the corresponding ClassInfo are performed for each instance of TableInfo. Next in step 1308, the system 100 performs a metadata query to get the PrimaryKeyInfo for each ClassInfo. Then in step 1310, the method performs the metadata query to get the foreign key information and creates the corresponding ComplexAttributeInfo for each instance of ClassInfo. Then in step 1312, the method continues for each ClassInfo by generating the Object Class Definitions 204 using the AttributeInfo and ComplexAttributeInfo. Finally, in step 1314, an ORM Specification 202 is created using the DatabaseInfo and all the instances of ClassInfo.

Referring now to Figures 14A and 14B, a flow chart of a preferred process for responding to an object call using the OR Mapping Unit 304 generated from the ORM Specification 202 is shown. The process begins in step 1402 with the system 100 testing whether an object call received through the Object Call Processing Unit 300 is a query. If the object call tested in step 1402 is determined to be a query, the method continues in step 1404. In step 1404, the method sets up the access planned data structure according to the query flags and query details in order to access referenced objects. Then in step 1406, the system 100 retrieves the base SELECT statement from ClassInfo. Next in step 1408, the method tests whether any predicate has been specified. If a predicate has been specified, the method continues from step 1408 to step 1410 before proceeding to step 1412. In step 1410, the method, in particular the OR Mapping Unit 304, translates the

specified predicate and appends the predicate as a WHERE clause. If a predicate has not been specified, the method continues directly from step 1408 to step 1412. In step of 1412, the SELECT statement including a WHERE clause, if any, produced by steps 1406 through 1410 is issued against the database 206. Next, the method continues in step 1414 by determining whether more rows are available from the database 206. If more rows are available from the database 206, the method continues in step 1416. Otherwise, the method proceeds to step 1424 and tests whether there are query objects from the subclasses. If there are additional query objects from the subclasses, the method returns to step 1406 to process the objects of subclasses. If there are not additional query objects from subclasses, then the method continues in step 1426 as will be described below.

If in step 1414, the process determined that more rows are available from the database 206, then the method continues to step 1416. In step 1416, the system 100 fetches the next row and creates an instance of a top-level object. Then in step 1418, the system 100 sets the attribute values from the corresponding column values. Then in step 1420, the method creates the required foreign key entries and associates them with target class structures. After step 1420, the method continues in step 1422 to determine whether the specified number of top-level objects have been created. If the method determines that the specified number of top-level objects have not been created, then the method continues back to step 1414 and loops through steps 1416 to 1420 until a top-level object is created for each row in the database 206. On the other hand, if the method determines that the specified number of top-level objects have been created,

then the method continues in step 1426. As shown in Figure 14B, the method continues with step 1426 by creating a SELECT statement and a WHERE clause using the foreign keys for each referenced target class. After step 1426, the method retrieves rows, creates target objects and links them with the referencing complex attributes in step 1428. Then in step 1430, the method creates a foreign key entry for each complex attribute of the target class before proceeding to step 1432. In step 1432, the method tests whether there are more foreign keys for target classes. If there are, the method returns to step 1428 and performs both step 1428 and 1430 for each foreign key. If it is determined in step 1432 that there are no more foreign keys for the target class, the method proceeds to step 1434. In step 1434, the method returns the list of top-level objects to the user and then the method ends.

Referring back to Figure 14A, if the object call tested in step 1402 is determined not to be a query, then the method assumes that it is an insert object call and proceeds to step 1440. Those skilled in the art will recognize that the present invention described in Figures 14A and 14B could be modified to handle updates and deletes in a similar fashion. In step 1440, the method sets up an access plan data structure as per insert flags and insert details for the accessing referenced objects. Next in step 1442, the method retrieves the INSERT statement from ClassInfo. In step 1444, the preferred process prepares an INSERT statement for the current connection to the database 206. Then in step 1446, the method finds its value and binds it with the column position for each AttribInfo. Next in step 1448, the process executes the INSERT statement to store the top-level objects. Finally, in step 1450 the method determines whether there are

more non-null referenced objects to be inserted. If there are more non-null referenced objects to be inserted, the method returns to step 1442 to create an INSERT statement for each of them. If there are not any more non-null referenced objects, the processing of the insert object call is complete.

Referring now to Figure 15, the novel and unique method for performing objects streaming will be described. As shown in Figure 15, the process begins with step 1502 by beginning a new transaction. Next in step 1504, the system 100 generates a query call to the Database Exchange Unit 210 for a plurality of objects with the streaming flag. The number of objects is preferably defined as n, and those skilled in the art will understand that the number of objects may be any number of objects that the user desires. Next in step 1506, the system 100 determines a query context (QC) for streaming. Then in step 1508, the system 100 invokes the query operation on the query context for a predetermined number (X) of objects. In step 1510, the method opens and saves in the query context the query cursor for the table of top-level class objects. Then in step 1512 the system 100 initiates the query processing to fetch the predetermined number (X) of objects. This is done by performing steps 1404 through 1434 as has been described above with reference to Figure 14. Then in step 1514, the query context is saved for this session of the Database Exchange Unit 210, and the objects are returned in step 1516. Next in step 1518 the objects are processed. In step 1520, the user may decide to get more objects through the current stream of objects. If the user does not want to get more objects through streaming, the method is moved to step 1522 by creating a "query close" call to the Database Exchange Unit 210. Then in step 1524, the saved

query cursor and query context are released. Finally, in step 1526, the "query close" call finishes and in step 1528 the transaction is committed to the database 206. If it is determined in step 1520 that the user decides to get more objects from the stream, then the preferred method proceeds through steps 1530 through 1538. In step 1530, the process generates a "query fetch" call for a second preferred number (m) of objects to the Database Exchange Unit 210. Next in step 1532, the process of the present invention invokes the query fetch operation on the saved query context for the second predetermined number of objects. In step 1534, the query cursor saved in the query context is retrieved for use. Then in step 1536, the query is processed to fetch m objects. Again, this step is identical to step 1512 and is done by performing steps 1404 to 1434. After step 1538, all of the m objects are returned and the process returns to step 1518 to process the m returned objects. After step 1518, the user may continue to use the stream of objects iteratively as described earlier until the whole stream is exhausted or the user does not need any more objects.

Referring now to Figure 16, a preferred method for using directed operations for a query operation is shown. This was described in the context of performing the step of creating the required foreign key entry and associating it with the target class structures from Figure 14A. Those skilled in the art will recognize that while the method for using directed operations is described here in the context of query operation, directed operations may be applied to insert, update and delete operations in a similar fashion. As shown in Figure 16, the sub-process begins in step 1604 by determining whether or not there are more complex attributes. If there are no more complex attributes, the

method is complete and continues onto step 1422 without any directed operations. However, if there are more complex attributes, then the method continues instead to 1606. In step 1606, the method determines whether this attribute of the class needs to be accessed as per the plan data structure. If in step 1606, the method determines that this attribute of the class does not need to be accessed according to the plan data structure then the process moves to step 1610 where the complex attribute is ignored before returning to step 1604. Otherwise, a foreign key entry is created and associated with the target class structure in step 1608 before the method returns to step 1604. This way the foreign key entries are made only for those complex attributes which need to be accessed as per the plan data specified by the user.

Referring now to Figures 20A-20D, block diagrams of various embodiments for architectural configurations of the present invention in different tiers (parts) of applications using different relational database management systems 206 are shown. In the exemplary embodiments shown below, the Database Exchange Unit 210 is preferably implemented in Java. Thus a variety of other embodiments will be understood to those skilled in the art.

Figure 20A shows a stand alone application 2000 which is using the Database Exchange Unit 210, that is preferably a class libraries which execute as part of the application process in the same Java Virtual Machine Process (VMP). This mode may be useful during prototyping or simple applications. The same application can easily be split into 2 tiers with the Database Exchange Unit 210 providing the second tier. This is similar to how the Database Exchange Unit 210 has been described above.

Figure 20B shows a CORBA/RMI application server 2004 which is using Database Exchange Unit 210 as class libraries that execute as part of the application server process in the same Java VM. The server 2004 is serving multiple clients 2002a, 2002b, 2002c, 2002d, and is using multiple back end RDBMSs 206a, 206b, 206c, and 206d.

Figure 20C shows multiple applications 216a, 216b, 216c attached to one Java Exchange server 2006 that is providing a multithreaded database exchange service for one RDBMS 206.

Figure 20D shows multiple applications 216a, 216b, 216c, 216d, 216e, 216f of which are attached to two different Database Exchange Units 210a, 210b that are providing database exchange services for multiple RDBMS 206a, 206b, 206c, 206d of different types. The Database Exchange Units 210a, 210b may be distributed over many machines to provide scalability. They may be co-located with an RDBMS 206 on the same machine (e.g., Database Exchange Unit 210b and Oracle RDBMS above) for improved data transfer.

Figures 21A-21B are graphic block diagrams of architectural configurations without and with the present invention. These Figures 21A-21B show the advantage of the present invention. Figure 21A shows the prior art where the database exchange units require hand coding to map the Java objects to existing RDBMSs. However, with the present invention all the hand coding is eliminated. With the simple declaration of the desired mappings between the object model and the relational model, the database exchange unit is automatically generated. Furthermore, the Database Exchange Unit

can be generated from an ORM Specification or reverse engineered from object models and relational schema.

Referring now to Figures 22A and 22B, flow charts of the preferred process for generating Named Sequence Generators 226 and using them to produce persistent object identification numbers are shown. As has been noted above, the Named Sequence Generators 226 preferably include an application program interface (API) for retrieving sequence numbers. For example, the API in Java is

```
"public long getNextSequence(String sequenceName, long
increment)  throws RemoteException, JDXException,"
```

In response, Named Sequence Generators 226 return the next available sequence number for the given 'sequenceName'. The persistent sequence number in the database 206 is incremented by 'increment' such that the calling application can safely assume that no other application would get the next sequence number in the range of (returned sequence number n, n+increment-1) both inclusive. In other words, this range (n, n+increment-1) presents a unique set of numbers with respect to the given sequenceName across all applications accessing the same RDBMS 206. These sequence numbers can typically be used to assign unique ids to different objects.

As shown in Figures 22A and 22B, the process has two portions: an initialization portion (design-time portion) and an execution portion (run-time portion). While the two portions of the process are shown and will be described as being performed in a linear manner, those skilled in the art will recognize that there may be a significant delay between performing initialization and performing execution. The initialization

process begins in step 2202 during schema generation as has been described above. During schema generation, the process creates a metadata table "jdxSequence" in the database 206. The metadata table "jdxSequence" preferably has the following format CREATE TABLE jdxSequence(seqName varchar(80), startingValue INT, jdxORMId varchar(80), maxIncrement INT, nextValue INT, CONSTRAINT JDX_PK_jdxSequence PRIMARY KEY (jdxORMId, seqName)). In other words, the method creates a table that indicates a sequence name, a starting value, a next value and an increment, along with other information. Next in step 2204, for each sequence generator defined in the <SEQUENCE-SPEC> the method creates an entry in the table jdxSequence. Once complete, the table identifies which sequence generators are available, and the rows in the table can be used for the generation of unique identification numbers, and this portion of the method is complete.

During execution, the method begins in step 2206 by receiving an object call to produce a new object or sequence id number. During runtime at the application level, a need often arises to get a range of unique sequence numbers (could be only one) such as to assign unique id numbers for new objects. Then in step 2208 the method receives a get next sequence number call from the application 216. Then in step 2210, the method starts an independent transaction for the given name sequence. Then in step 2212, the method increments the value of nextValue column with the given "increment" value for the sequence name. The method then commits the independent transaction to the database 206 in step 2214. In response in step 2216, the database 206 returns the value n which equals next value minus the increment. Finally, in step 2218, the application 216

uses the range of numbers generated by the system 100 at the application level. For example, the unique sequence ID name can be produced using the sequence name and the returned values.

While the present invention has been described with reference to certain preferred embodiments, those skilled in the art will recognize that various modifications may be provided. These and other variations upon and modifications to the preferred embodiments are provided for by the present invention.

Appendix A

Explanations and Examples of construct of the ORM Grammar

<REMARK-SPEC> ::= REM [<any remarks>]

Explanation: Any line starting with REM is considered a remark (comment) line and it is ignored.

Example: REM This is a comment

<ORM-INFO> ::= [;ORMId=<ORMId>] [;ORMFile=<fileName>]

Explanation: <ORMId> specifies the Object Relational Mapping id of a specification. The default <ORMId> is the string "defaultORMId". The Object-Relational Mapping information (metadata) stored in the database corresponding to the given <ORMId> is used for subsequent processing.

An ORMFile specification overrides the mapping information corresponding to <ORMId>. This is an easy way to experiment with different mappings before storing that information permanently in the database.

Example: See <DATABASE-URL> below.

<DATABASE-URL> ::= <regularURL>[<ORM-INFO>]

Explanation: <DATABASE-URL> consists of the url (uniform resource locator, which includes database name, user name and password among other things) of the database to be connected to, optionally followed by ORM specific information <ORM_INFO>. <ORM_INFO> is used to initialize the database with the Object-Relational Mapping information or to retrieve the Object-Relational Mapping information from the database.

Example: See <DATABASE-SPEC> below.

<ENDDATABASE-SPEC> ::= ;

Explanation: This is just a delimiter to signify the end of <DATABASE-SPEC>

<DATABASE-SPEC> ::= DATABASE <DATABASE-URL> <ENDDATABASE-SPEC>

Explanation: A <DATABASE-SPEC> specifies the database and the Object-Relational Mapping (metadata) information to be used. Please see <DATABASE-URL> above for more details.

Example: DATABASE jdbc:odbc:sqlpubs; user=guest; password=hello; ORMId=pubs01;

or

DATABASE jdbc:odbc:sqlpubs; user=guest; password=hello; ORMFile=pubs.jdx;

The first example specifies the use of Object-Relational Mapping information stored in the database corresponding to the ORMId "pubs01"

The second example specifies that the Object-Relational Mapping information should be retrieved from the file pubs. jdx

<PRIMARY-KEY-SPEC> ::= PRIMARY_KEY {<attribName> . . . }

Explanation: A <PRIMARY-KEY-SPEC> identifies the attribute names whose combined values uniquely identify a particular object. For a collection object, it specifies the attributes whose values are the same for all the objects in the collection.

Example: PRIMARY_KEY pub_id

or

PRIMARY_KEY title_id lorange

<REFERENCE-KEY-SPEC> ::= REFERENCE_KEY <referenceKeyName> {<attribName> . . . }

Explanation: A <REFERENCE-KEY-SPEC> identifies the attribute names whose combined values uniquely identify a particular object. This may be an alternate way of identifying objects of a particular class. <REFERENCE-KEY-SPEC> is not allowed for collection classes.

Example: REFERENCE_KEY name fname minit lname

Here we are defining a reference key "name" consisting of three attributes - fname, minit and lname.

```
<SQLMAP-SPEC> ::= SQLMAP FOR <attribName>
                  [COLUMN_NAME <columnName>]
                  [SQLTYPE <sqlType>]
                  [NULLABLE]
```

Explanation: Through <SQLMAP-SPEC>, one can refine the mapping of a class attribute to SQL column in one of the following ways - use a column name different than the attribute name, use an SQL data type different than the default SQL data type for the attribute type, allow the column to be nullable. Allowing mapping of an attribute name to a different column name may be handy if the existing column name is cryptic and we want a more meaningful attribute name at the class

definition level. Semantic knowledge of the data may be used to improve the storage efficiency for an attribute by specifying a more refined SQL type. For example, a String attribute (zipCode) may be mapped to varchar(10) instead of default varchar(255).

Some object-oriented languages like Java provide facility of reflection whereby the attribute names for a class and their types may be determined programmatically. If that is not the case, then a <SQLMAP-SPEC> needs to be specified for each attribute. Otherwise, some default mapping may be done using reflection facility.

Example: SQLMAP FOR prInfo COLUMN_NAME pr_info SQLTYPE text

or

SQLMAP FOR zip SQLTYPE varchar(10)

```
<RELATIONSHIP-SPEC> ::=  RELATIONSHIP <attribName>
                         REFERENCES <targetClassName>
                         {EMBEDDED | [BYVALUE] [REFERENCED_KEY
                         <referencedKeyName>]WITH<attribName>. . .}
```

Explanation: <RELATIONSHIP-SPEC> is used to provide details for a complex attribute.

EMBEDDED keyword means that the value of a complex attribute is embedded in a large binary column of the same table where rest of the primitive attributes are stored. This may be an optimized way for storing a referenced object if that referenced object does not need to be retrieved in any other context.

A Non-embedded complex attribute references a regular class or a collection class identified by <targetClassName>.

BYVALUE keyword implies that the referenced object (may be a collection object) does not have an independent existence without the existence of the containing object. When a containing object is stored, all the objects referenced through its BYVALUE complex attributes are also stored in the database. If a containing object is deleted, its BYVALUE referenced objects should also be deleted.

<referenceKeyName> specifies the name of a reference key of the class <targetClassName>. By default, referencing is done to the PrimaryKey of the target class.

The list of <attribName> is an ordered enumeration of the source attributes in the current class which are

used to find the target class objects through the reference key. The data types of the source attributes should be compatible with the data types of the attributes defining the reference key in the target class.

Example: RELATIONSHIP titles REFERENCES ArrayTitle BYVALUE WITH pub_id

or

RELATIONSHIP job REFERENCES Job REFERENCED_KEY PrimaryKey WITH job_id

The first specification means that the complex attribute 'titles' references an object of type ArrayTitle (which is a collection (array) of Title objects). The referenced object is contained in the current object by value. The attribute pub_id of the containing class is used to identify the (default primary key of the) referencing object.

The second example specifies that the complex attribute 'job' references an object of class 'Job' with the referencing object's attribute 'job_id' which should match the primary key attribute of the class 'Job'.

```
<ENDCLASS-SPEC> ::= ;
```

Explanation: This is just a delimiter to signify the end of a <CLASS-SPEC> or a <COLLECTION-CLASS-SPEC>.

```
<CLASS-SPEC> ::= CLASS<className>[TABLE<tableName>]<PRIMARY-KEY-SPEC>
                    [<REFERENCE-KEY-SPEC> .  .  .  ]
                    [<SQLMAP> .  .  .  ]
                    [<RELATIONSHIP-SPEC> .  .  .  ]
                    <ENDCLASS-SPEC>
```

Explanation: A <CLASS-SPEC> encapsulates all the Object-Relational Mapping information about one class. The <tableName> specifies the name of the relational table which holds the instances of this class. The default <tableName> is the same as the <className>. Other specifications have been explained earlier. Please note that it is mandatory to specify <PRIMARY-KEY-SPEC> for a class.

Example:

```
CLASS Title TABLE titles
PRIMARY_KEY title_id
RELATIONSHIP royscheds REFERENCES ArrayRoySched
BYVALUE WITH
```

```
            title_id
        SQLMAP FOR price SQLTYPE Money
        ;

<ORDERBY-SPEC> ::= ORDERBY {<attribName> .   .   .   }
```

Explanation: An <ORDERBY-SPEC> of a <COLLECTION-CLASS-SPEC> specifies an ordered list of attributes whose values are used to sequence the objects in a collection during retrieval.

Example: ORDERBY ytd_sales title_id

The above specification for the collection class ArrayTitle means that such a collection of objects (e. g. in the titles attribute of a Publisher class object) should be ordered as per the values of ytd_sales and title_id attributes of the Title objects in the collection.

```
<COLLECTION-CLASS-SPEC> ::= COLLECTION_CLASS <className>
COLLECTION_TYPE {ARRAY | VECTOR}
    ELEMENT_CLASS <elementClassName>
                    [ELEMENT_TABLE <elementTableName>]
                    <PRIMARY-KEY-SPEC>
```

[<ORDERBY-SPEC>]

<ENDCLASS-SPEC>

Explanation: A <COLLECTION-CLASS-SPEC> encapsulates all the Object-Relational Mapping information about a collection class. A collection is actually a pseudo-class; there may not be an actual class by that name in the program.

The COLLECTION_TYPE specifies how the objects in the collection are combined together - in an array or in a vector.

The <elementClassName> specifies the class whose instances form the collection. Even the instances of a subclass of the <elementClassName> class may participate in a collection.

The mandatory <PRIMARY-KEY-SPEC> specifies the attributes which are the basis for realizing a collection. The values of these attributes are the same for all the objects in a collection.

The <elementTableName> specifies the name of the relational table which holds the instances of the collection objects. The default table is the same as the table for <elementClassName> class.

Other specifications have been explained earlier.

Example:

```
COLLECTION_CLASS ArrayRoySched COLLECTION_TYPE ARRAY
ELEMENT_CLASS
   RoySched
PRIMARY_KEY title_id
ORDERBY royalty
;
```

<ORM-SPEC> ::= <DATABASE-SPEC>

Any combination of <CLASS-SPEC>

<COLLECTION-CLASS-SPEC>,

<SEQUENCE-SPEC> and <REMARK-SPEC>

Explanation: An Object-Relational Mapping specification <ORM-SPEC> consists of <DATABASE-SPEC> followed by any combination of <CLASS-SPEC>, <COLLECTION-CLASS-SPEC> and <REMARK-SPEC>. This is what an <ORMFile> contains. The following example has an ORMId of pubs01. This specification is contained in a file (pubs. jdx).

Example:

```
DATABASE
jdbc:odbc:sqlpubs;user=guest;password=hello;ORMId=pub
s01
```

```
;
REM
CLASS RoySched TABLE roysched
PRIMARY_KEY title_id lorange
;
COLLECTION_CLASS ArrayRoySched COLLECTION_TYPE ARRAY
   ELEMENT_CLASS RoySched
PRIMARY_KEY title_id
ORDERBY royalty
;
CLASS Title TABLE titles
PRIMARY_KEY title_id
RELATIONSHIP royscheds REFERENCES ArrayRoySched
BYVALUE WITH
   title_id
SQLMAP FOR price SQLTYPE Money
;
COLLECTION_CLASS ArrayTitle COLLECTION_TYPE ARRAY
ELEMENT_CLASS
   Title
PRIMARY_KEY pub_id
ORDERBY ytd_sales title_id
```

```
;
CLASS PubInfo TABLE pub_info
PRIMARY_KEY pub_id
SQLMAP FOR logo SQLTYPE image
SQLMAP FOR prInfo COLUMN_NAME pr_info SQLTYPE text
;
CLASS Publisher TABLE publishers
PRIMARY_KEY pub_id
RELATIONSHIP pubInfo REFERENCES PubInfo BYVALUE WITH
pub_id
RELATIONSHIP titles REFERENCES ArrayTitle BYVALUE
WITH pub_id
;
CLASS Job TABLE jobs
PRIMARY_KEY job_id
;
CLASS Emp TABLE employee
PRIMARY_KEY emp_id
RELATIONSHIP job REFERENCES Job REFERENCED_KEY
PrimaryKey WITH
   job_id
RELATIONSHIP publisher REFERENCES Publisher WITH
pub_id
```

```
;
CLASS TitlePub
PRIMARY_KEY title_id
;
CLASS LinkList TABLE linklist
PRIMARY_KEY link_id
RELATIONSHIP next REFERENCES LinkList BYVALUE WITH
next_link_id
;
```

```
<SEQUENCE-SPEC> ::= SEQUENCE <sequenceName>
                    MAX_INCREMENT <maxIncrementValue>
                    [START_WITH <startingVal>]
```

Explanation: A <SEQUENCE-SPEC> defines a sequencer which can provide chunks of persistently unique sequence numbers.

<maxIncrementValue> is used to do sanity-check against requests which may erroneously ask for a large chunk of sequences which may quickly reduce the availability of new sequence numbers.

Optional <startVal> specifies the starting sequence number provided through this sequencer. The

default is 1.

Example: SEQUENCE seqFoo MAX_INCREMENT 100 or

SEQUENCE seqBar MAX_INCREMENT 1000 START_WITH 10001

The second sequencer (seqBar) starts with a value of 10001.

Appendix B

Concepts used in an Exemplary Object Model or Object Class Definitions

For the purpose of describing different concepts, the examples of (Java) class definitions given in the Figure 19 use Java. These classes have been defined using the sample database 'pubs' which comes with Microsoft SQL Server relational database management system.

Primitive and complex attributes

A primitive attribute of a class is an instance variable of simple (primitive) type. For example, attributes of type integer, String, boolean are primitive attributes. In the Figure 19, title_id and ytd_sales of class Title are primitive attributes.

A complex attribute is a reference to an object (or a collection of objects) of another class. For example pubInfo and tiltes of class Publisher are complex attributes.

In general, all instances of a class are stored in the same relational table. Primitive attributes are stored in the columns of that class. The appropriate SQL data type of the column may be different However, a complex attribute is not (cannot be) stored in the same table. Instead, the object(s) referenced by a complex attribute is stored in the table of the corresponding class. To subsequently retrieve those referenced objects as part of the containing object, a set of attributes of the containing object is used (as foreign key) to locate them. If a complex attribute is referencing a collection of objects, their ordering may be specified.

Containment by value

All primitive attributes are contained by value in an object. That is, they cannot exist independent of the object. Objects referenced by a complex attribute that cannot logically exist without the existence of the referencing (containing) object are also said to be contained by value. If the containing object is deleted, the contained by value objects should also be deleted. pubInfo and titles are examples of attributes contained by value in the class Publisher.

Containment by reference

A complex attribute which points to an object which may exist independent of the existence of the referencing (containing) object is an attribute contained by reference. If the referencing (containing) object is deleted, the referenced object need not be deleted. The publisher attribute of Emp class is contained by reference.

Collection class

A collection class is a pseudo-class describing a certain type (array or vector) of collection of objects of a given class. A collection class has an optional notion of ordering of elements of the collection. Collection class specification is needed to describe those complex attributes which reference a collection (array or vector) of objects. This is needed only for object relational mapping specification; no explicit class is defined at the language level.

Shallow and Deep queries

When an object is normally retrieved from the database, it is retrieved with all the complex attributes instantiated with referenced objects (recursively). This is called deep query. If none of the referenced objects are retrieved (i. e. only the primitive attributes are retrieved) , it is called a shallow query.

Directed operation options

Sometimes, just deep or shallow options may not be the most optimal way of doing an operation (query, insert, update, delete). For example, if an object has 5 complex (reference) attributes and we are interested in getting just 2 of them, how do we specify that? The answer is directed options. Directed options further qualify the depth of the operation in one of the following ways: 1) if the overall operation is deep, one may specify a list of class and attribute name pairs such that all except those complex attributes should be followed and 2) if the overall operation is shallow, one may specify a list of class and attribute name pairs such that only those complex attributes should be followed. Depending upon the application needs at certain stage of processing, these options may be employed to achieve efficiency or some semantic requirements.

Database URL

A database URL contains the URL (Universal Resource Locator) understood by the appropriate JDBC driver. Additionally, it has user name and password components.

Optionally, it has information about Object-Relational Mapping Id (ORMId) and/or Object-Relational Mapping File (ORMFile). They have been explained further under the grammar rules of <DATABASE-URL> in a subsequent section.

Appendix C

Application Programming Interface Examples

APIs (Java style) that can conveniently be used to deal with persistence of objects. None of these APIs assumes knowledge of SQL.

void open(String databaseURL)

Opens the database connection and intializes the data structures as per the Object-Relational Mapping specification corresponding to an ORMId or an ORMFile specified in the databaseURL.

Vector query(String className, String predicate, long maxObjects, long queryFlags, Vector queryDetails)

Returns a list of objects of the given class satisfying the given search condition (predicate). If maxObjects is -1 then all the relevant objects are returned else upto a maximum of maxObjects objects are returned. queryFlags, among other things, specifies if it is a deep query (i.e., all the referenced objects are also retrieved) or shallow query (i.e., just the top-level object is retrieved) Default behavior is deep query. If queryFlag is set for the streaming mode then maxObjects are returned and additional objects may be retrieved using queryFetch() API described below. QueryDetails parameter specifies directed operation options which may be used to control the query in different ways.

Vector queryFetch(long maxObjects, long queryFlags, Vector queryDetails)

Returns a list of upto maxObjects following objects from the object stream opened by a previous call to query(). This is allowed in the same transaction in which the query() call was initiated. QueryDetails parameter specifies directed options which may be used to control the query in different ways.

void queryClose()

Closes the current object stream.

public void insert(Object object, long insertFlags, Vector insertDetails)

Inserts the given object and all its referenced objects that are contained by value. InsertFlags specifies if it is a deep insertion (i.e., all the referenced by value objects are also inserted) or shallow insertion (i.e., just the top-level object is inserted). Default behavior is deep insert insertDetails parameter specifies directed options that may be used to further control the insert operation in different ways.

public void update(Object object, long updateFlags, Vector updateDetails)

Updates the given object and all its referenced objects which are contained by value. The default update semantics are such that the existing persistent copy of the object in the database is replaced by the new updated object. updateFlags

specifies if it is a deep update (i. e., all the referenced by value objects are also updated) or shallow update (i. e., just the top-level object is updated). Default behavior is deep update. updateDetails parameter specifies directed options which may be used to further control the update operation in different ways.

public long update2(String className, String predicate, Vector newValues, long updateFlags)

Updates all objects of the given class satisfying the given search condition (predicate) as per the new attribute values. NewValues parameter is a vector of names and values of updated attributes. (Only shallow update in this case). Returns the number of updated objects.

public void delete(Object object, long deleteFlags, Vector deleteDetails)

Deletes the given object and all its referenced objects which are contained by value. deleteFlags specifies if it is a deep delete (i. e., all the referenced by value objects are also deleted) or shallow delete (i. e., just the top-level object is deleted). Default behavior is deep delete.

public long delete2(String className, String predicate, long deleteFlags)

Deletes all objects of the given class satisfying the given search condition (predicate). deleteFlags specifies if it is a deep delete (i. e., all the referenced by value objects are also deleted) or shallow delete (i. e., just the top-level object is

deleted). Default behavior is deep delete. Returns the number of deleted objects.

public long getNextSequence(String sequenceName, long increment)

throws RemoteException, JDXException;

Returns the next available sequence number for the given sequenceName. The persistent sequence number in the database is incremented by `increment' such that the calling application can safely assume that no other application would get the next sequence number in the range of (returned sequence number n, n+increment-1) both inclusive. In other words, this range (n, n+increment-1) presents a unique set of numbers with respect to the given sequenceName across all applications accessing the same RDBMS. These sequence numbers can typically be used to assign unique ids to different objects.

Appendix D

Extensions to the Object-Relational Mapping System of the Present Invention

A. Extension for Security (login and access rights)

1: Specifying login rights for users with respect to an ORM Specification

Currently any user who can login to the database can access database elements and also the objects provided through the current invention of object-relational mapping. However, this access may be further restricted by providing a login mechanism at the level of ORMId identifying a particular ORM Specification. This would enhance the security at the higher level whereby the number of users may be restricted at the level of object domain of an ORM Specification identified by an ORMId.

Implementation details:

This feature may be implemented by keeping a table with the following 3 columns:

ORMId	varchar(80)
userName	varchar(80)
password	varchar(80)

The Object Administrator owns this table and maintains entries in this table as per security requirements.

Essentially, at the time of opening a service with an ORMId specification, the supplied user name and password would be checked against this table to determine if the user is authorized to use the ORM Specification.

2: Specifying access rights for users with respect to an ORM Specification

Currently access rights (read, write etc.) on databases elements (tables, views, stored procedures) may be defined for users accessing the database. However, if relational data is exposed as objects then the current mechanism does not lend itself well in terms of defining access rights based on object definitions. With ORM specification mechanism of the current invention, it would be very convenient and innovative to add access rights at 2 levels:

1: High level - Access rights are granted at the level of ORMId. A user may be assigned read or write access for a particular ORM specification identified by an ORMId and here are some possible rules:

- If the user has not been given any access rights, the user cannot use Database Exchange Unit for that ORM Specification.
- If the user has been given only read access, the API calls for insert, update, delete and SQL Statement cannot be executed by that user.
- Otherwise, the user can execute all API calls for all the classes identified in the ORM Specification.

2: Low level - Access rights are granted at the level of ORMId and a class within the ORM specification identified by the ORMId. The rules as above apply however the restrictions are observed at individual class levels.

Grammar for specifying access rights for objects:

Some of the Define new rules in ORM Grammar to specify the name of a stored procedure and the class of the objects which can be constructed using the returned values from the execution of the stored procedure. Here is an example of a rule:

<ACCESS-RIGHT> ::= ACCESS_RIGHT <USER-NAME> ACCESS_TYPE {READ | WRITE | EXECUTE} [<CLASS-NAME>]

For example:

ACCESS_RIGHT dPeriwal ACCESS-TYPE WRITE

or

ACCESS_RIGHT jSmith ACCESS-TYPE READ Employee

The first specification grants all accesses to the user dPeriwal. The second one grants just the READ access on only the Employee class objects to the user jSmith.

Implementation details:

- ORM Data Structure Creation Unit will create a structure in memory for each such

specification and during the execution of the API call, this data structure would be consulted to execute the stored procedure, create objects from the stored procedure result set and return the objects to the application.

B. Extension for Relational Stored Procedures

Mapping for stored procedures

Currently stored-procedures are used to define programs which can be executed in the relational database engine itself providing better performance for executing some business logic. Often times the output of these stored procedures are returned to the application program in the form of a single value or a set of values (as multiple rows). It would be advantageous for an object-oriented program to invoke stored procedures for performance reasons and get the returned values as program objects. So the current invention can be enhanced in the following manner:

Grammar for specifying mapping for stored procedures:

Define new rules in ORM Grammar to specify the name of a stored procedure and the class of the objects which can be constructed using the returned values from the execution of the stored procedure. Here is an example of a rule:

<SP-SPEC> ::= SP_CLASS <CLASS-NAME> STORED_PROC <STORED-PROCEDURE-NAME>

For example:

SP_CLASS abc STORED_PROC proc1

The above specification states that the output of the stored procedure "proc1" should be used to produce objects of class "abc"

API for invoking stored procedures:

An object-oriented program can use the following API to invoke a stored procedure and retrieve resulting objects. The API is similar to query API:

Vector storedProc (String spName, Vector parameters, long maxObjects, long spFlags)

where parameters are used to pass input values to the stored procedures.

Implementation details:

- ORM Data Structure Creation Unit will create a structure in memory for each such specification and during the execution of the API call, this data structure would be consulted to execute the stored procedure, create objects from the stored procedure result set and return the objects to the application.

WHAT IS CLAIMED IS:

1. A system for exchanging data between an object-oriented system and a relational system having tables defining a relational model, the system comprising:

at least one object class definition defining an object model;

an object relational mapping data structure defining a mapping between the object model and the relational model, the object relational mapping data structure produced from a declarative ORM Specification based on an ORM grammar;

an exchange unit for translating data from the object model to the relational model and for translating data from the relational model to the object model.

2. The system of claim 1, wherein the exchange unit further comprises:

an object call processing unit having inputs and outputs for receiving object calls and beginning the translation of the object calls, an input and an output of the object call processing unit coupled to the object-oriented system;

a mapping unit having inputs and outputs for performing the object-relational mapping according to the object relational mapping specification in response to signals from the object call processing unit, the mapping unit having inputs coupled to the object class definition, the object relational mapping data structure, and input and outputs the object call processing unit; and

a database interface unit having inputs and outputs, for retrieving and storing data in the relational system, the inputs and outputs coupled to the relational system and the mapping unit.

3. The system of claim 2 wherein the object call processing unit intercepts Application Programming Interface (API) level calls for object manipulation and executes the API level calls using the mapping unit.

4. The system of claim 1, wherein the exchange unit further comprises:

an object relational mapping specification defining a mapping between the object model and the relational model, the object relational mapping specification including a plurality of a declarative ORM grammar statements; and

an ORM Data Structure creation unit having inputs and an output for producing the object relational mapping data structure, the inputs of the ORM Data Structure creation unit coupled to receive the object class definition, the object relational mapping specification, and the database interface unit, the output of the ORM Data Structure creation unit coupled to the input of the mapping unit for providing the object relational mapping data structure.

5. The system of claim 1, further comprising a schema generator, the schema generator having inputs and outputs for generating a file of commands applicable on the relational system that implement the object call, the input of the schema generator

coupled to the object class definition and the object relational mapping data structure, the output of the schema generator coupled to the relational system.

6. The system of claim 5, wherein the schema generator further comprises:

an ORM Data Structure creation unit having inputs and an output for producing the object relational mapping data structure, the inputs of the ORM Data Structure creation unit coupled to receive the object class definition and the object relational mapping specification;

a relational schema statements generation unit having an input and an output, the input of the relational schema statements generation unit coupled to the output of the ORM Data Structure creation unit for receiving the object relational mapping data structure, the relational schema statements generation unit producing a file of statements that will produce the relational schema in the relational system; and

a relational schema statements application unit having an input and an output for applying statements to the relational system, the input of the relational schema statements application coupled to the output of the relational schema statements generation unit for receiving the file of statements that will produce the relational schema in the relational system, the output of the relational schema statements application unit coupled to the input of the database interface unit for applying the statements on the relational system.

7. The system of claim 1, wherein the relational system is a relational database management system.

8. The system of claim 7, further comprising:

a plurality of RDBMS Tables stored in the relational system, the plurality of RDBMS Tables setting forth the organization and structure of the data in the relational model in addition to describing certain functionality provided by the relational model; and

a plurality of ORMMetadata Tables stored in the relational system, the plurality of ORMMetadata Tables storing additional object relational specifications.

9. The system of claim 1 further comprising a schema reverse-engineering unit for creating object class definitions and an object relational mapping specification using a database schema.

10. The system of claim 9, wherein the schema reverse-engineering unit further comprises:

an ORM template specification containing names of tables to be used for generating object class definitions;

database metadata inquiry unit for accessing the relational system to retrieve metadata including a schema for the relational model and information about the object model, the database metadata inquiry unit coupled to the relational system; and

reverse engineering ORM structure creation unit for producing an object relational mapping data structure from metadata, the reverse engineering ORM structure creation unit coupled to the output of the database metadata inquiry unit to receive the metadata and coupled to receive the ORM template specification.

11. The system of claim 10, wherein the schema reverse-engineering unit further comprises an ORM specification generation unit for producing an ORM specification from the object relational mapping data structure, the ORM specification generation unit coupled to the object relational mapping data structure.

12. The system of claim 10, wherein the schema reverse-engineering unit further comprises an object class definitions generation unit for producing the object class definitions from the object relational mapping data structure, the object class definitions generation unit coupled to the object relational mapping data structure.

13. The system of claim 1, further comprising a named sequence generator for generating persistently unique sequence numbers, the named sequence generator having inputs and outputs, the named sequence generator coupled to the relational system for and coupled to the object-oriented system by the exchange unit.

14. The system of claim 1, wherein the object relational mapping data structure includes a mapping for a stored procedure executable by an engine in the relational system, the stored procedure being invokable by an application program

using the exchange unit and creating an object with a value returned by executing the stored procedure.

15. The system of claim 1, wherein the system further comprises a security unit having inputs and outputs for determining whether a user can use the ORM Specification and a scope for use of the ORM Specification, the security unit coupled to control access to the object relational mapping data structure and the exchange unit.

16. A method for generating an object relational mapping data structure, the method comprising the steps of:

determining whether an object relational mapping file has been specified;

if an object relational mapping file has been specified, using an object relational mapping specification identified by the object relational mapping file as the identified object relational mapping specification;

if an object relational mapping file has not been specified, determining an ORM identification name, retrieving an object relational mapping specification corresponding to the ORM identification name from a relational database, and using the retrieved object relational mapping specification as the identified object relational mapping specification; and

creating an object relational mapping data structure using the identified object relational mapping specification.

17. The method of claim 16 wherein the step of determining an ORM identification name further comprises the steps of:

determining whether an ORM identification name has been specified;

using the ORM identification name specified if an ORM identification name has been specified; and

using a default ORM identification name specified if an ORM identification name not has been specified.

18. A method for generating object relational mapping data structures from an object relational mapping specification includes the steps of:

retrieving an object relational mapping specification;

creating an instance of a plurality of data structures defining a mapping between an object model and a relational model;

overriding default mappings using a SQL map specification;

using additional specifications to create additional data structures;

retrieving Metadata from a database to enhance the plurality of data structures;

matching class information for object-oriented model with the plurality of data structures;

generates SQL statements for each class; and

generates inserts and update statements to apply SQL statements to the database.

19. The method of claim 18, wherein the step of creating an instance of a plurality of data structures includes the steps of:

creating an instance of DatabaseInfo;

creating an instance of Tableinfo and ClassInfo for each class specification;

creating instance of CollectionClassInfo for each collection specification; and

creating the instances of AttribInfo for each ClassInfo.

20. The method of claim 19, wherein the step of using additional specifications to create additional data structures includes the steps of:

using primary-key and reference-key specifications to create instances of ReferenceKeyinfo; and

using the relationship specification to create instances of ComplexAttributeInfo.

21. The method of claim 20, wherein the step of matching class information comprises the step of matching AttribInfo with ColumnInfo.

22. A method for generating relational schema from an ORM specification and object class definitions, the method comprising the steps of:

retrieving an object relational mapping specification;

retrieving an object class definitions;

creating an instance of a plurality of data structures defining a mapping between an object model and a relational model;

overriding default mappings using a SQL map specification;

using additional specifications to create additional data structures; and

adding relational information to the data structures for each primitive and embedded attribute of the object-oriented model.

23. The method of claim 22, wherein the step of creating an instances of a plurality of data structures includes the steps of:

creating an instance of DatabaseInfo;

creating an instance of Tableinfo and ClassInfo for each class specification;

creating an instance of CollectionClassInfo for each collection specification; and

creating the instances of Attribinfo for each ClassInfo.

24. The method of claim 23, wherein the step of using additional specifications to create additional data structures includes the steps of:

using primary-key and reference-key specifications to create instances of ReferenceKeyinfo; and

using the relationship specification to create instances of ComplexAttributeInfo.

25. The method of claim 23, wherein the step of adding adds ColumnInfo in Tableinfo for each primitive and embedded attribute of each ClassInfo.

26. The method of claim 23, wherein the step of generating statements for producing and modifying tables in relational database includes the steps of:

generating a create table statement and primary key constraints statement in a CREATE file for each Tableinfo;

generating unique key and referential key constraint statements in an ALTER file for each ClassInfo; and

generating alter table drop constraint statements and drop table statements in a

DROP file for each ClassInfo.

27. The method of claim 26, wherein the step of executing the generated statements on the database includes the step of executing the DROP, CREATE and ALTER files to modify the database.

28. A method for generating an ORM specification and object class definitions from a database schema, the method comprising the steps of:

generating object relational mapping data structures using an ORM template specification;

performing at least one metadata query to retrieve information for the object relational mapping data structures;

generating an object class definition using the object relational mapping data structures; and

creating an ORM Specification using object relational mapping data structures.

29. The method of claim 28 wherein the step of generating object relational mapping data structures comprises the steps of:

creating an instance of DatabaseInfo; and

creating an instance of ClassInfo and TableInfo for each class in the ORM Template Specification.

30. The method of claim 28 wherein the step of performing at least one metadata query includes the steps of:

performing a metadata query and creation of ColumnInfo and AttributeInfo in the corresponding ClassInfo for each instance of TableInfo;

performing a metadata query to get the PrimaryKeyInfo for each ClassInfo;

performing a metadata query to get the foreign key information and create the corresponding ComplexAttributeInfo for each instance of ClassInfo;

31. The method of claim 28 wherein the step of creating an ORM Specification using object relational mapping data structures is done using the DatabaseInfo and all the instances of ClassInfo.

32. A method for responding to an object call using a mapping unit, the method comprising the steps of:

determining the type of object call;

setting up an access plan data structure according to flags settings;

creating a command statement for accessing relational system; and

issuing the command statement on relational system;

33. The method of claim 32 further comprising the step of processing the data from the relational system to provide it to the object-oriented system.

34. The method of claim 32 wherein the step of determining the type of object call includes the step of determining whether the object call is a query.

35. The method of claim 32 wherein the step of setting up access plan data structure according to flags settings includes the step of setting up the access plan data

structure according to the query flags and query details in order to access referenced objects.

36. The method of claim 33 wherein the step of setting up access plan data structure according to flags settings includes the step of setting up the access plan data structure as per insert flags and insert details for accessing referenced objects.

37. The method of claim 32 wherein the step of creating command statement for accessing relational system further comprises the steps of:

retrieving a base SELECT statement from ClassInfo;

testing whether any predicate has been specified; and

translating a specified predicate and appending the predicate as a WHERE clause, if a predicate has been specified;

38. The method of claim 37 wherein the step of issuing the command statement on relational system includes issuing the SELECT statement including a WHERE clause, if any, against a database of the relational system.

39. The method of claim 38 further comprising the step of:

determining whether more rows are available from the database;

if more rows are available from the database,

fetching a next row and creating an instance of a top-level object;

setting attribute values from corresponding column values;

creating required foreign key entries and associating them with target class structures;

determining whether there are query objects from the subclasses;

if there are additional query objects from the subclasses, repeat the steps of creating command statement for accessing relational system and issuing the command statement on relational system for the objects of subclasses;

40. The method of claim 39 wherein the step of processing the data from the relational system to provide it to the object-oriented system includes the steps of:

creating a SELECT statement and a WHERE clause using the foreign keys for each referenced target class;

retrieving rows and creating target objects and linking them with referencing complex attributes;

creating a foreign key entry for each complex attribute of the target class; and

returning a list of top-level objects to the application.

41. The method of claim 32 wherein the step of creating command statement for accessing relational system further comprises the steps of:

retrieving an INSERT statement from ClassInfo;

preparing the INSERT statement for the current connection to the database; and

finding the value for each AttribInfo and binding it with the column position for each AttribInfo.

42. The method of claim 41, wherein the step of issuing the command statement on relational system includes issuing the INSERT statement to store top-level

objects in the relational system.

43. The method of claim 42, wherein the step of issuing the INSERT statement to store top-level objects in the relational system, further comprises the steps of:

determining whether there are non-null referenced objects to be inserted,

creating an additional INSERT statement for each non-null referenced objects if there are non-null referenced objects to be inserted; and

issuing the additional INSERT statements.

44. A method for object streaming comprising the steps of:

beginning a new transaction;

generating a query call to a database exchange unit for a plurality of objects;

returning the predetermined number (X) of objects;

processing the returned objects;

determining whether more objects are to be retrieved through the current stream of objects;

retrieving and processing an additional number (m) of objects if more objects are to be retrieved through the current stream of objects;

generating a query close to the database exchange unit; and

committing the transaction to the database.

45. The method of claim 44 for object streaming further comprising the steps of:

determining a query context (QC) for streaming;

invoking a query operation on the query context for a predetermined number (X) of objects;

saving in the query context, the query cursor for the table of top-level class objects;

initiating a query processing to fetch the predetermined number (X) of objects; and

saving the query context for this session.

46. The method of claim 44 wherein the step of retrieving and processing an additional number (m) of objects further comprises the steps of:

generating a "query fetch" call for the additional number (m) of objects to the database exchange unit;

invoking a query operation on the saved query context for the additional number (m) of objects;

retrieving the query cursor saved in the query context;

processing the query to fetch the additional number (m) of objects;

returning the additional number (m) of objects; and

processing the returned additional number (m) of objects.

A SYSTEM AND METHOD FOR EXCH ANGING DATA & COMMANDS BETWEEN AN OBJECT ORIENTED SYSTEM AND A RELATIONAL SYSTEM

ABSTRACT OF THE DISCLOSURE

A system for exchanging data and commands between an object oriented system and a relational system. The system includes an Object-Relational Mapping (ORM) grammar, an ORM specification, Object Class Definitions, a relational database, an operating system, a Database Exchange Unit including an OR mapping unit, a schema generator, a schema reverse engineering unit and applications. The ORM specification is based on the ORM grammar and includes information for defining the mapping between object-oriented system and the relational system. The Object Class Definitions define the object-oriented system, and the relational database defines the relational system. The Database Exchange Unit executes in accordance with the ORM specification, and is the programs/routines that operate to translate data from the object model to the relational model, and vice versa. The present invention further comprises a number of methods including: a method for generating a ORM Data Structures; a method for generating a mapping unit; a method for generating a schema from an object model and an object-relational mapping specification; a method for generating an Object Class Definitions and an ORM specification from an ORM template specification and database schema; and a method for object streaming, and methods for efficient generation of persistently unique sequence numbers for new objects.

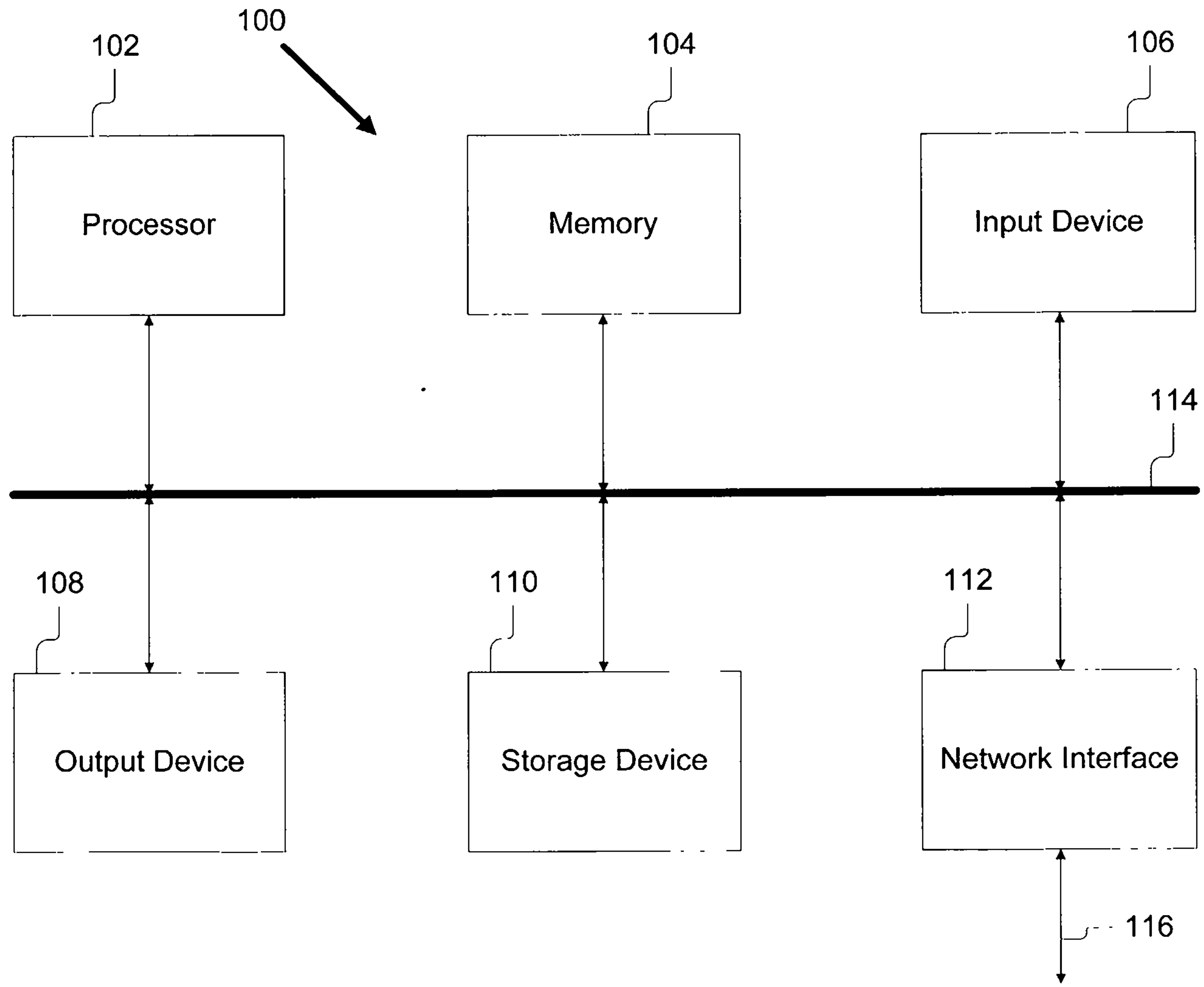

100
102
Processor
104
Memory
106
Input Device
114
108
Output Device
110
Storage Device
112
Network Interface
116

Figure 1

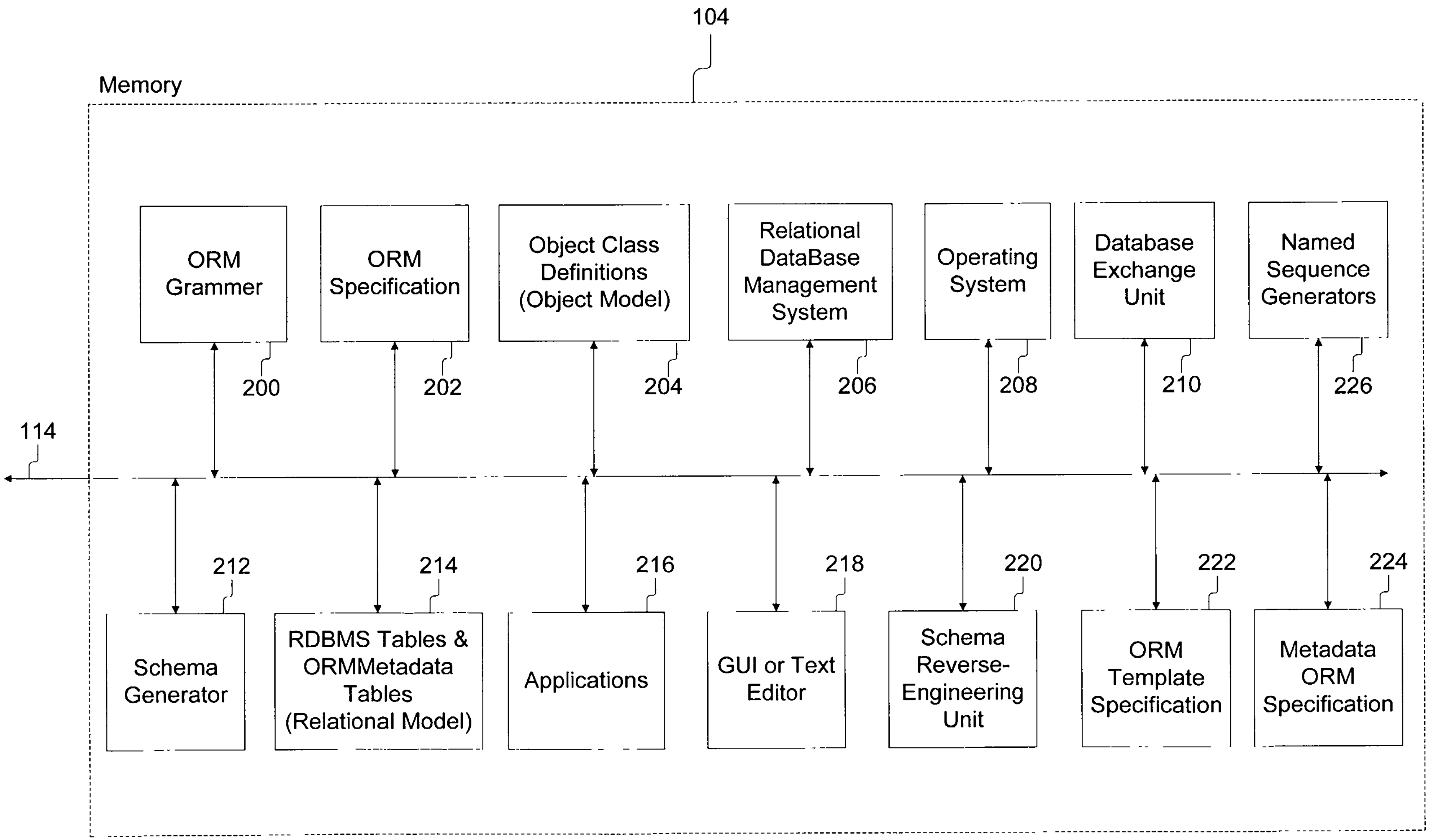

104
Memory
114
ORM Grammer
200
ORM Specification
202
Object Class Definitions (Object Model)
204
Relational DataBase Management System
206
Operating System
208
Database Exchange Unit
210
Named Sequence Generators
226
212
Schema Generator
214
RDBMS Tables & ORMMetadata Tables (Relational Model)
216
Applications
218
GUI or Text Editor
220
Schema Reverse-Engineering Unit
222
ORM Template Specification
224
Metadata ORM Specification

Figure 2

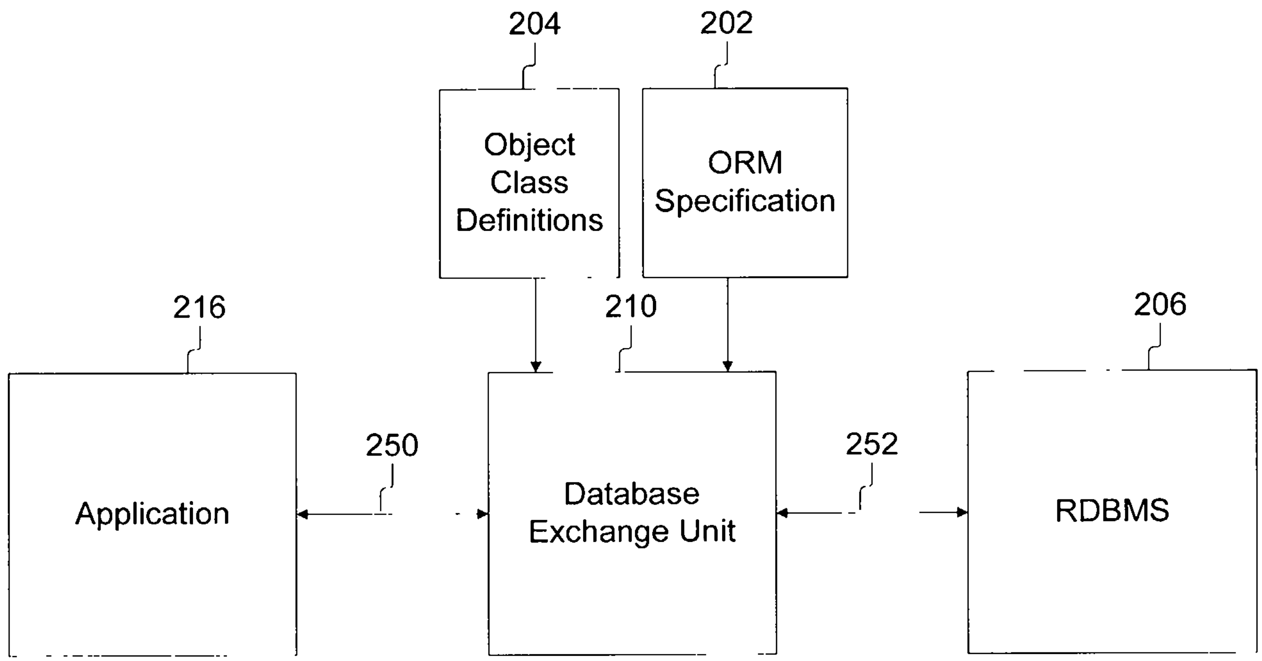

204
Object
Class
Definitions
202
ORM
Specification
216
Application
250
210
Database
Exchange Unit
252
206
RDBMS

Figure 3

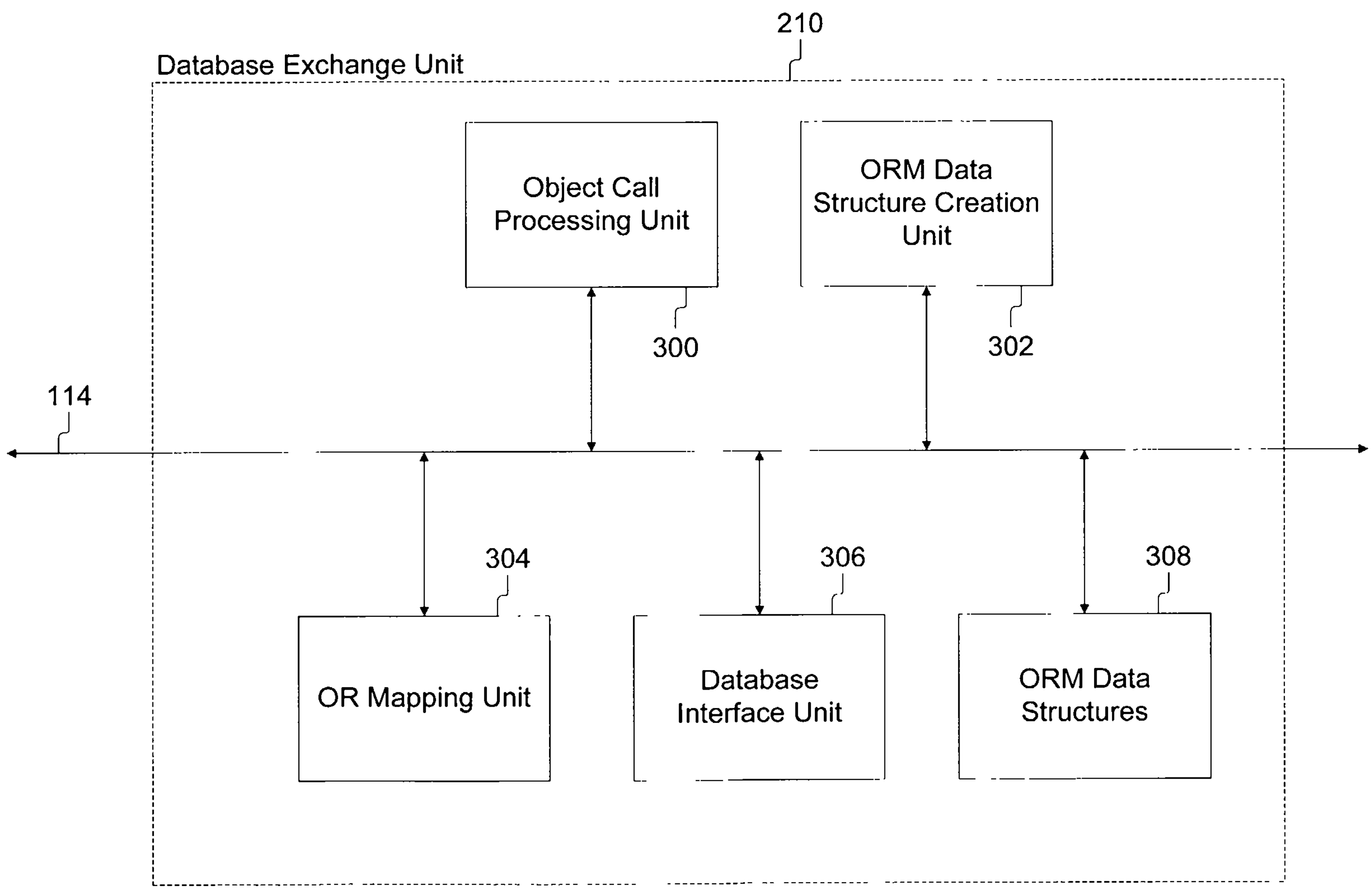

210
Database Exchange Unit
Object Call Processing Unit
ORM Data Structure Creation Unit
300
302
114
304
306
308
OR Mapping Unit
Database Interface Unit
ORM Data Structures

Figure 4

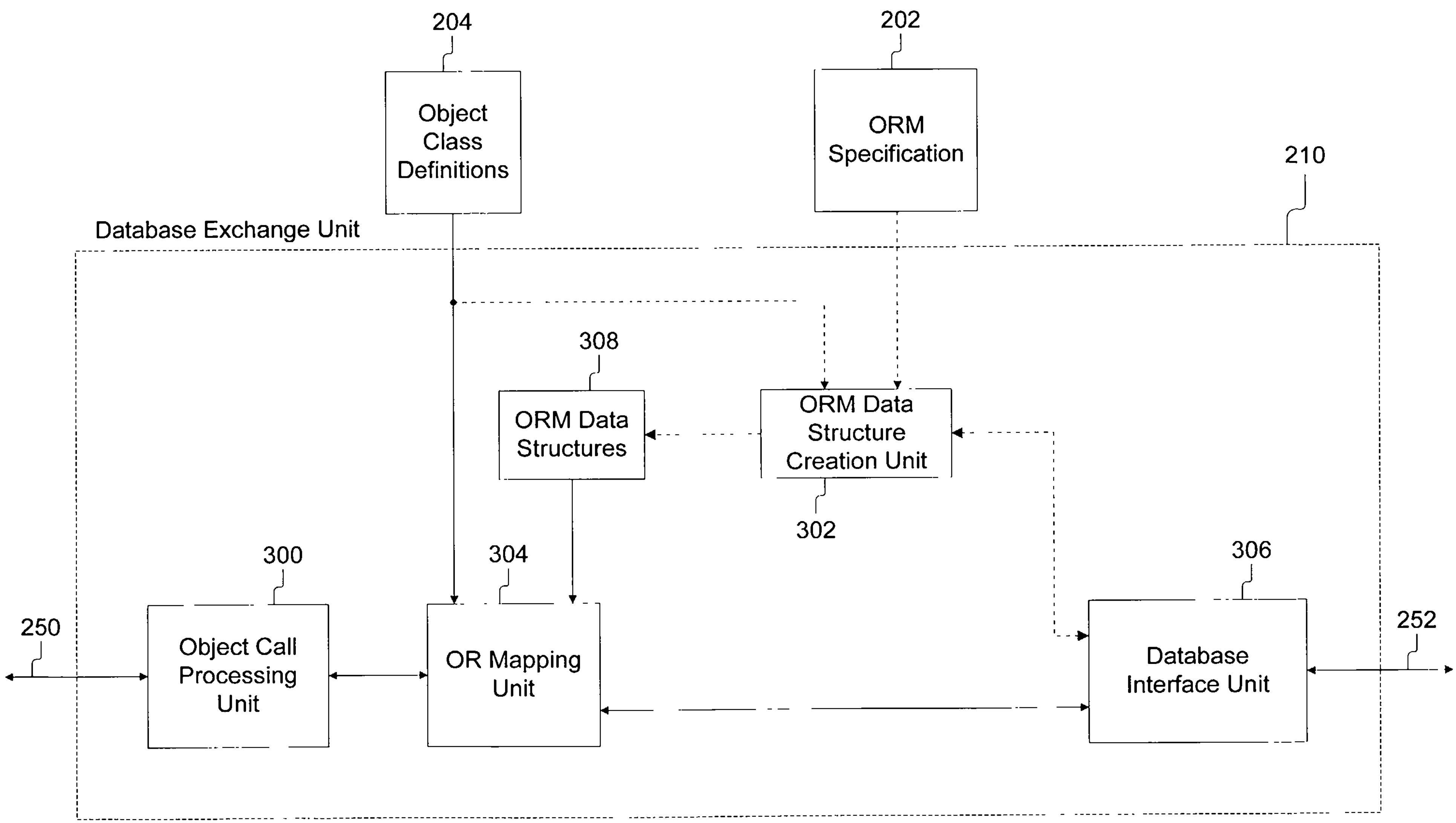

204
Object Class Definitions
202
ORM Specification
210
Database Exchange Unit
308
ORM Data Structures
ORM Data Structure Creation Unit
302
300
304
306
250
Object Call Processing Unit
OR Mapping Unit
Database Interface Unit
252

Figure 5

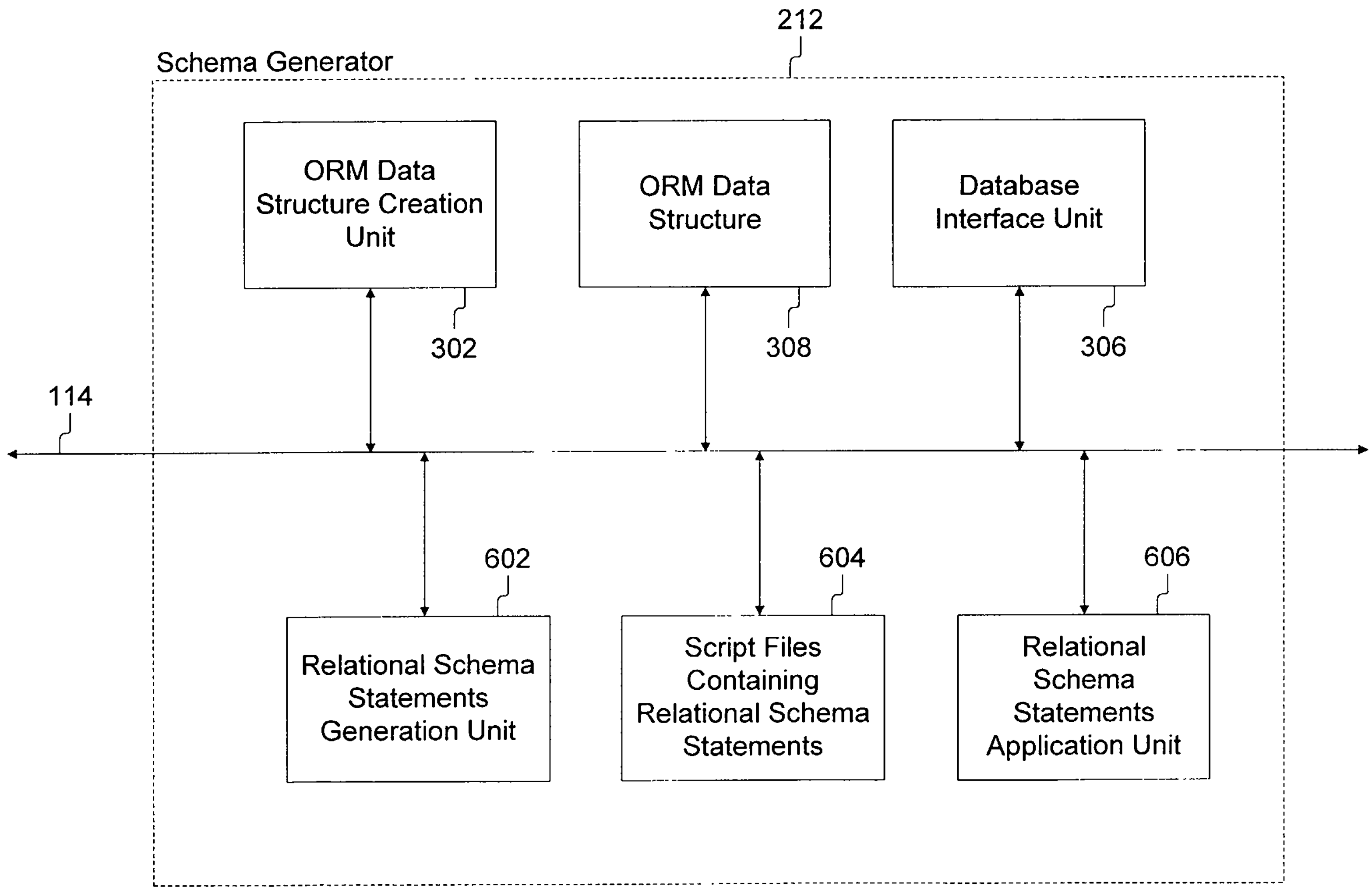

212
Schema Generator
ORM Data Structure Creation Unit
302
ORM Data Structure
308
Database Interface Unit
306
114
602
Relational Schema Statements Generation Unit
604
Script Files Containing Relational Schema Statements
606
Relational Schema Statements Application Unit

Figure 6

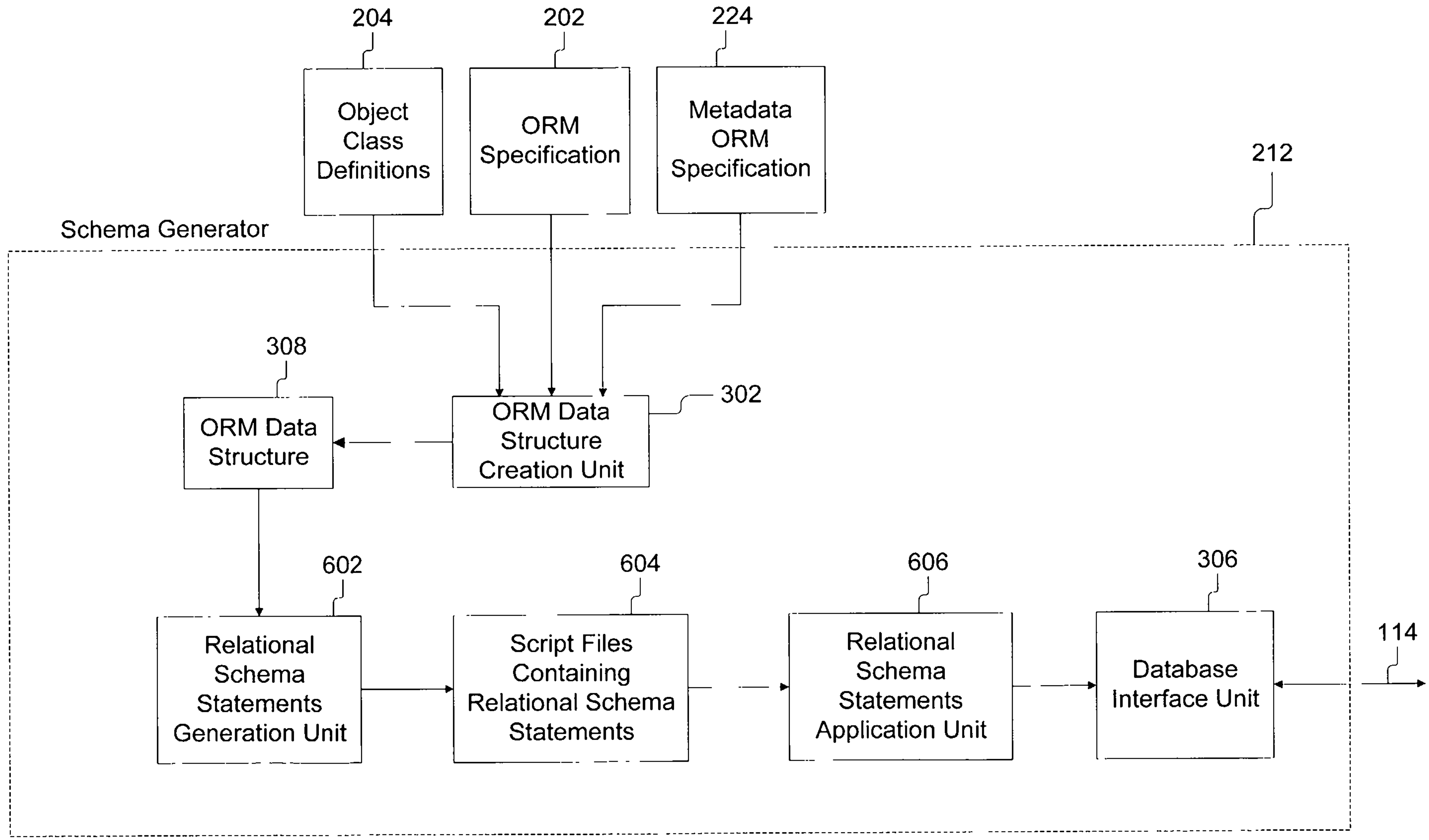

204
Object Class Definitions
202
ORM Specification
224
Metadata ORM Specification
212
Schema Generator
308
ORM Data Structure
ORM Data Structure Creation Unit
302
602
Relational Schema Statements Generation Unit
604
Script Files Containing Relational Schema Statements
606
Relational Schema Statements Application Unit
306
Database Interface Unit
114

Figure 7

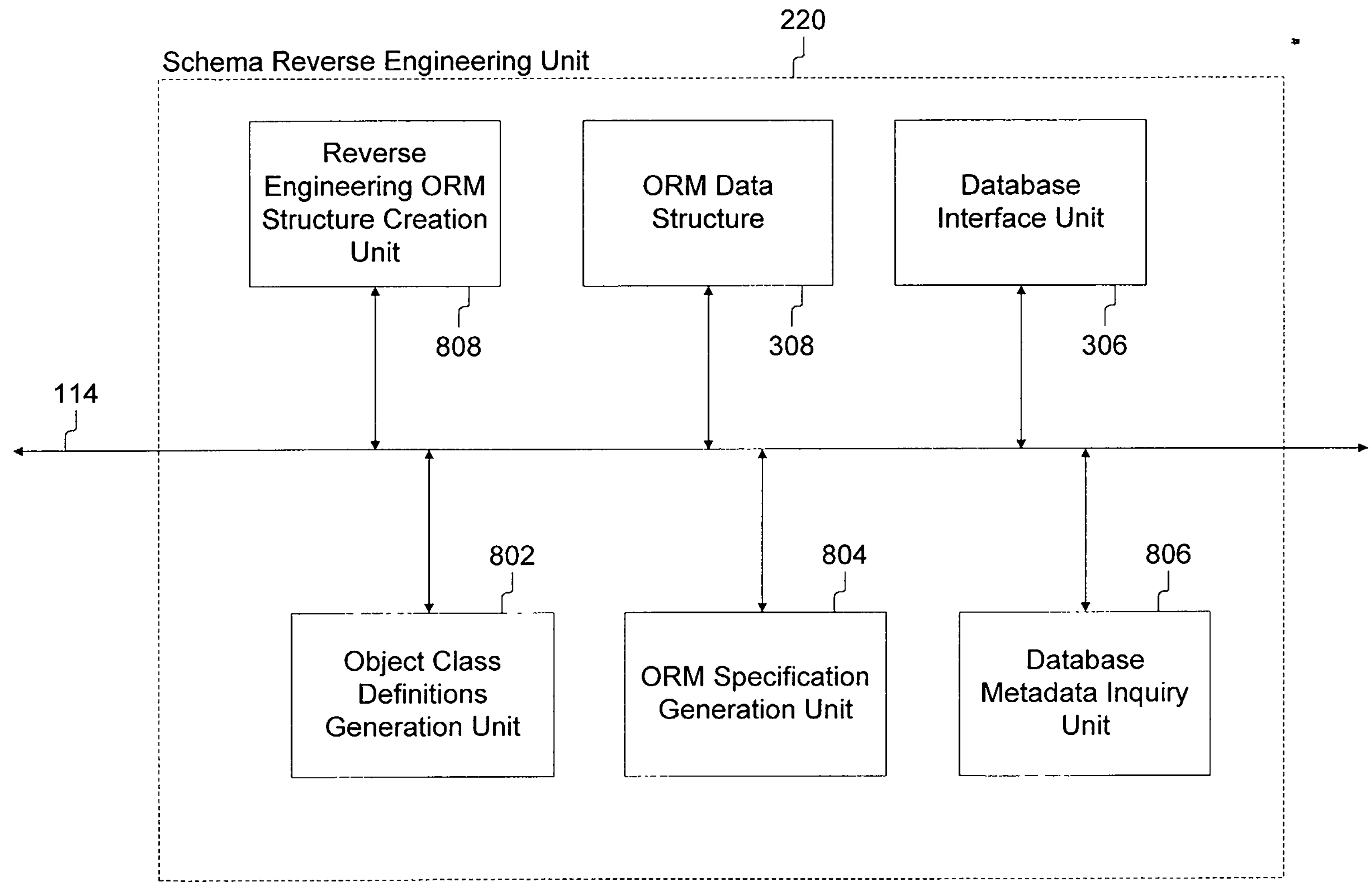

Schema Reverse Engineering Unit
220
Reverse Engineering ORM Structure Creation Unit
808
ORM Data Structure
308
Database Interface Unit
306
114
802
Object Class Definitions Generation Unit
804
ORM Specification Generation Unit
806
Database Metadata Inquiry Unit

Figure 8

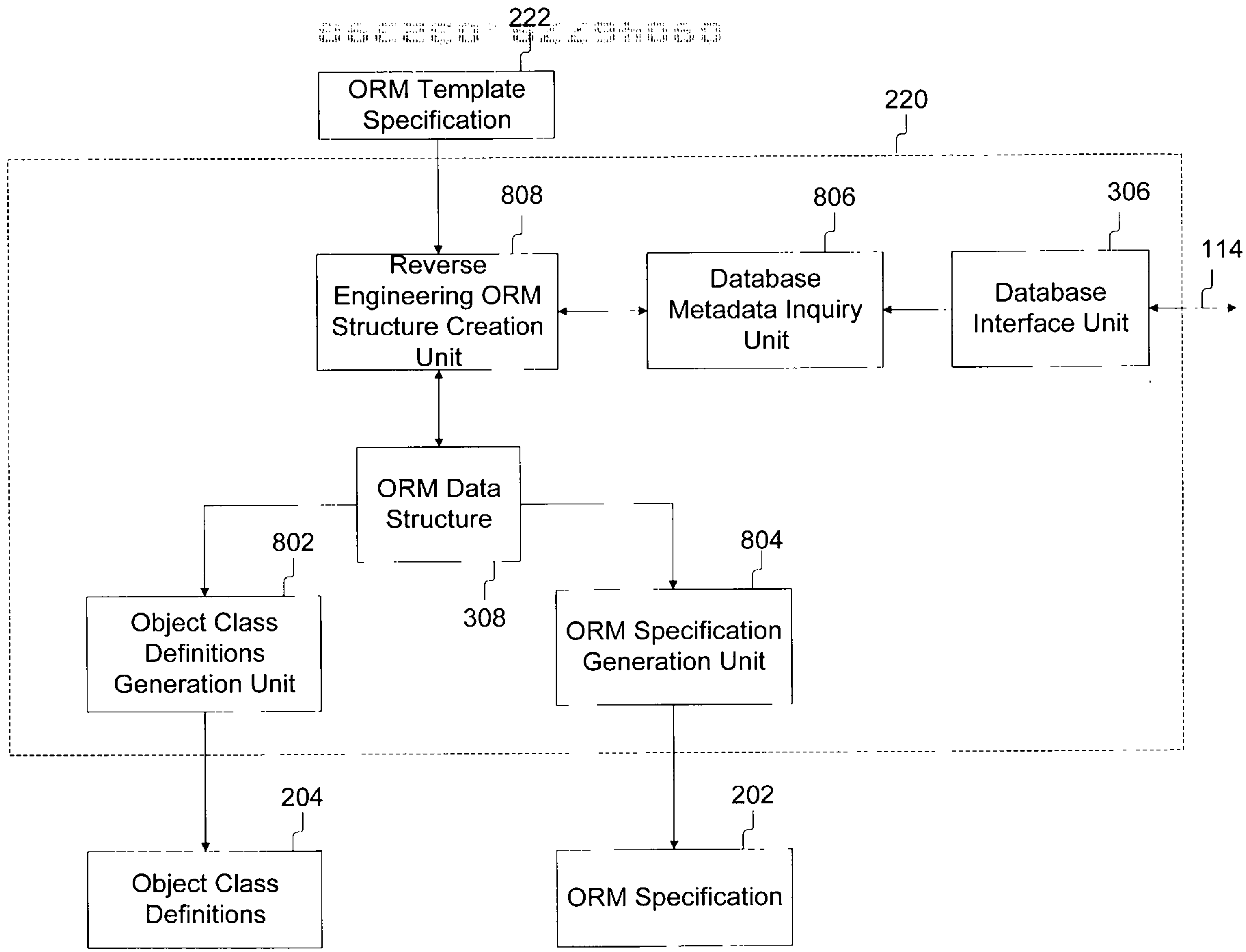

222
ORM Template Specification
220
808
806
306
114
Reverse Engineering ORM Structure Creation Unit
Database Metadata Inquiry Unit
Database Interface Unit
ORM Data Structure
308
802
804
Object Class Definitions Generation Unit
ORM Specification Generation Unit
204
202
Object Class Definitions
ORM Specification

Figure 9

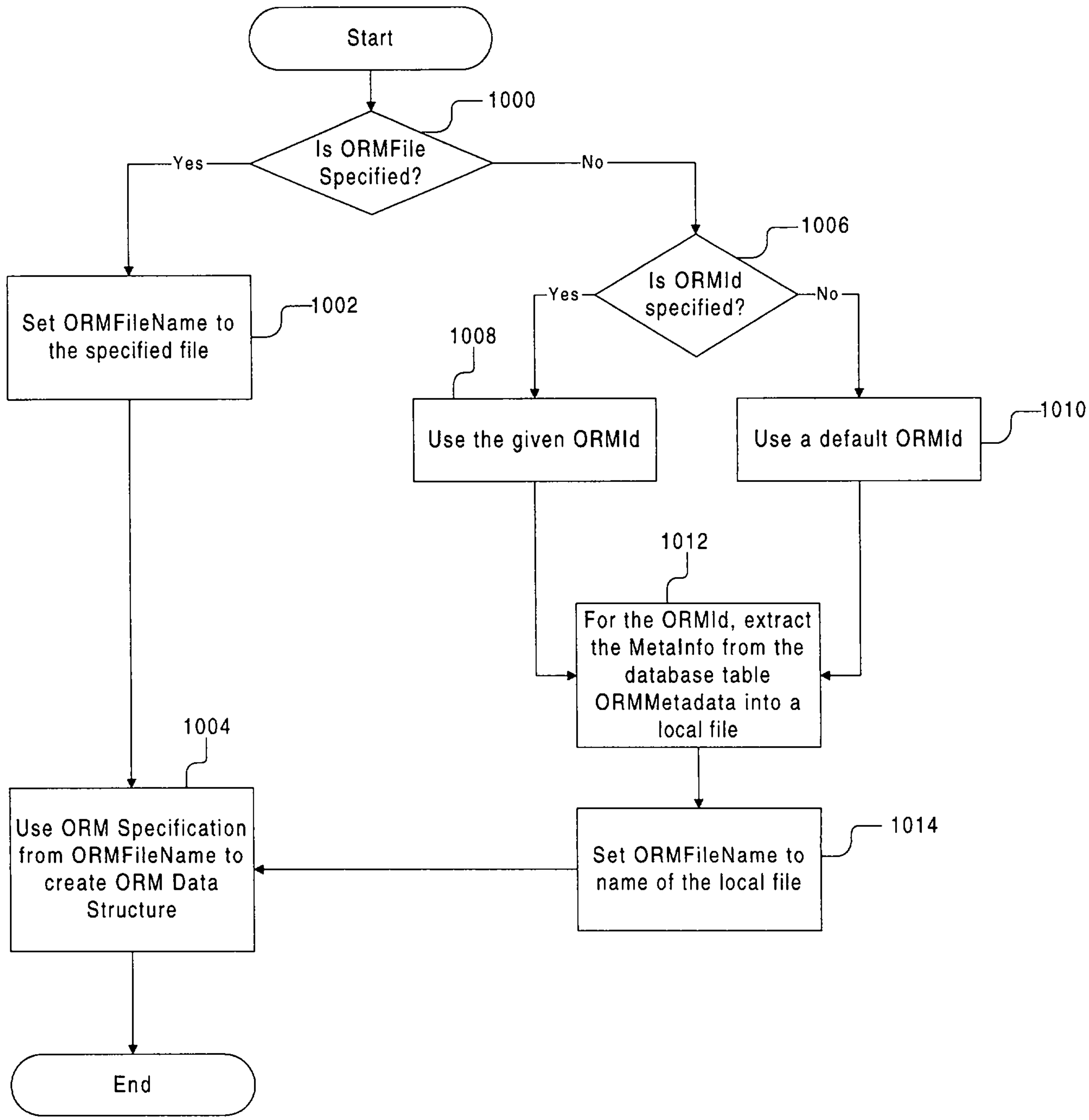
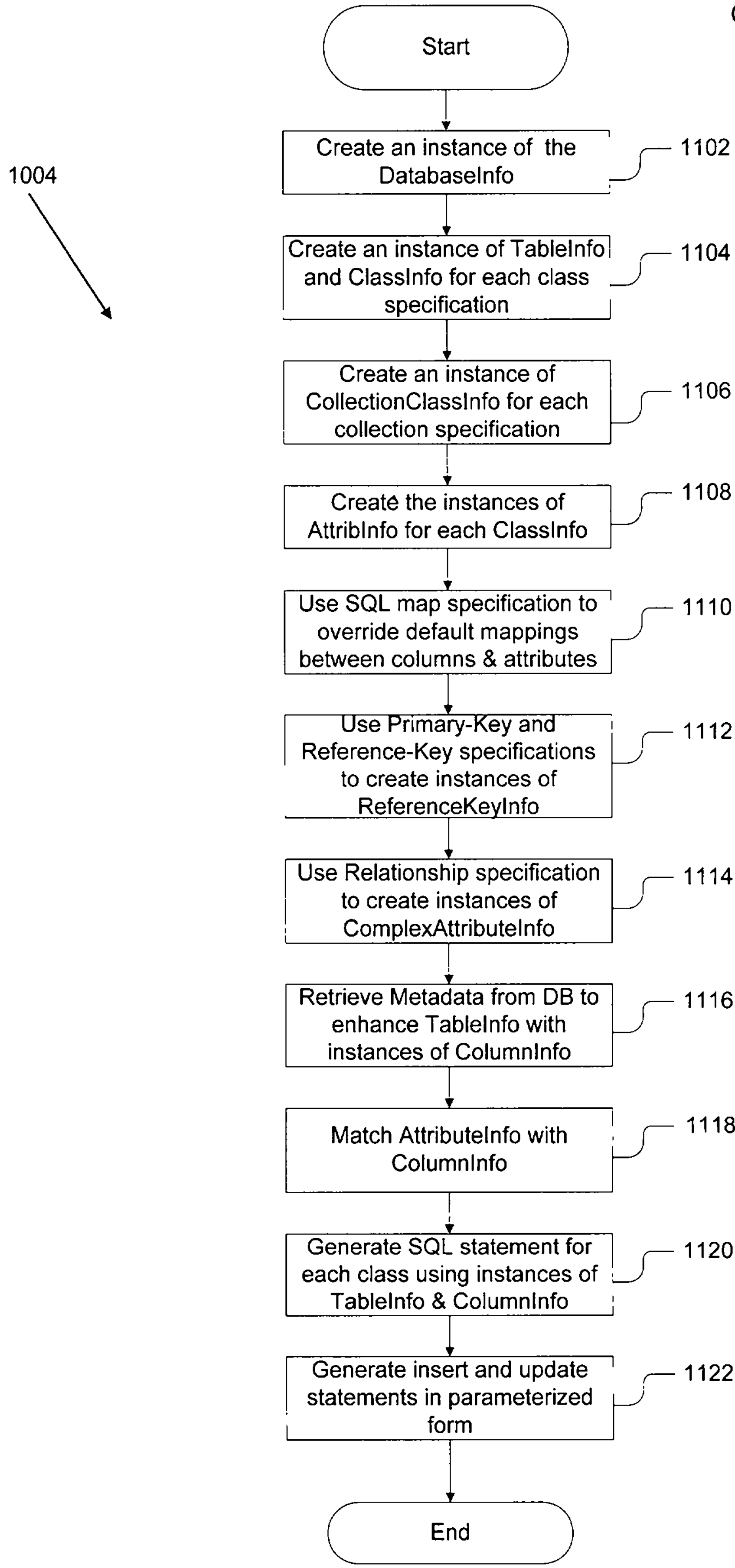


Figure 10

Method for using ORM specification based on an existing ORMid or an ORMfile to create an ORM Data Structure

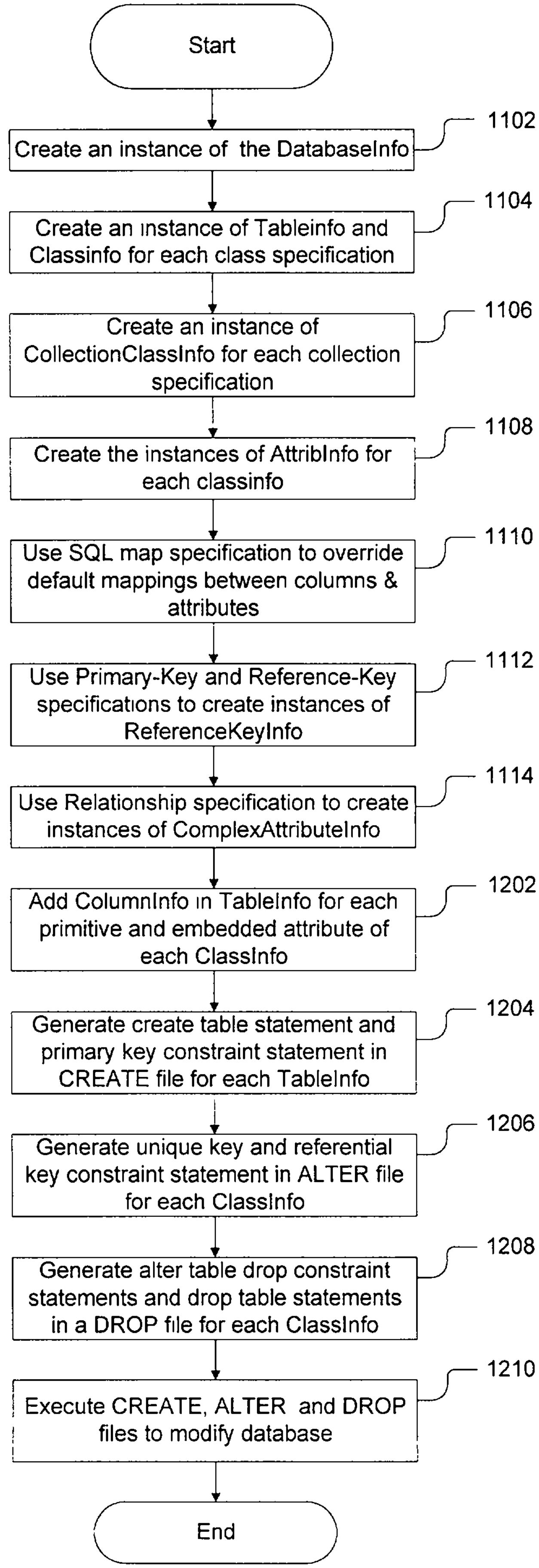
Method For Generating ORM Data Structures from an ORM Specification and Object Class Definitions

Figure 11



Method for generating relational schema from an ORM specification and Object Class Definitions

Figure 12



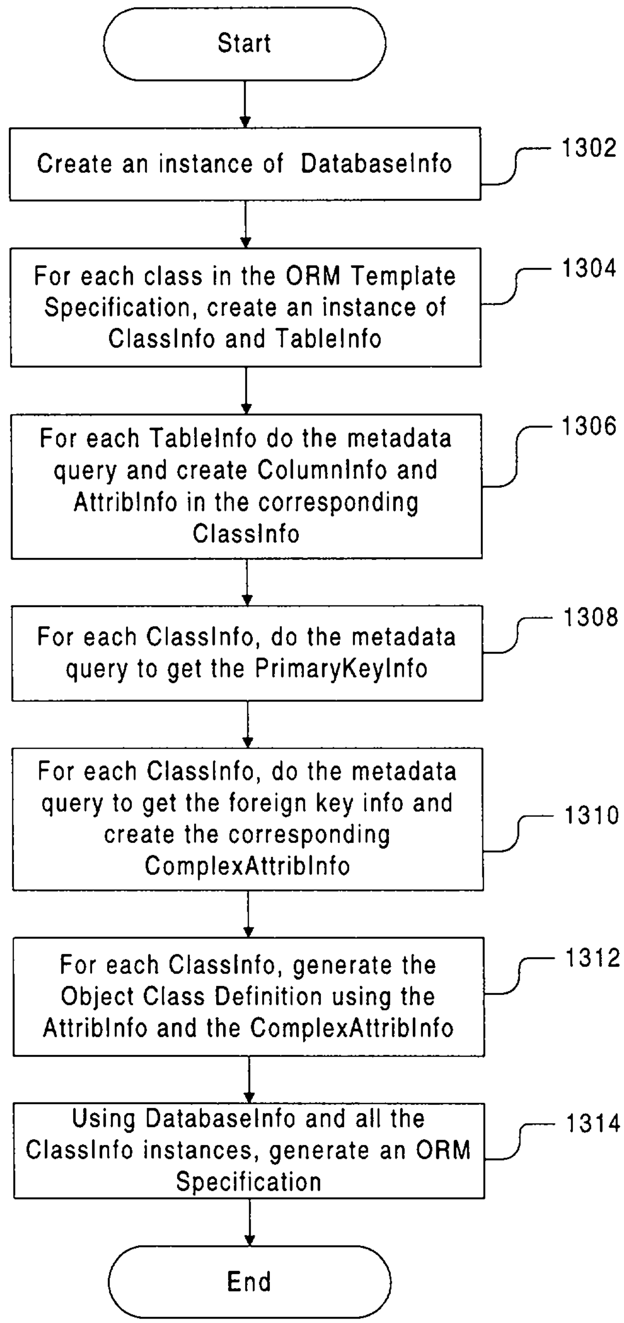


Figure 13

Method for generation of an ORM Specification and an Object Class Definition from a database schema

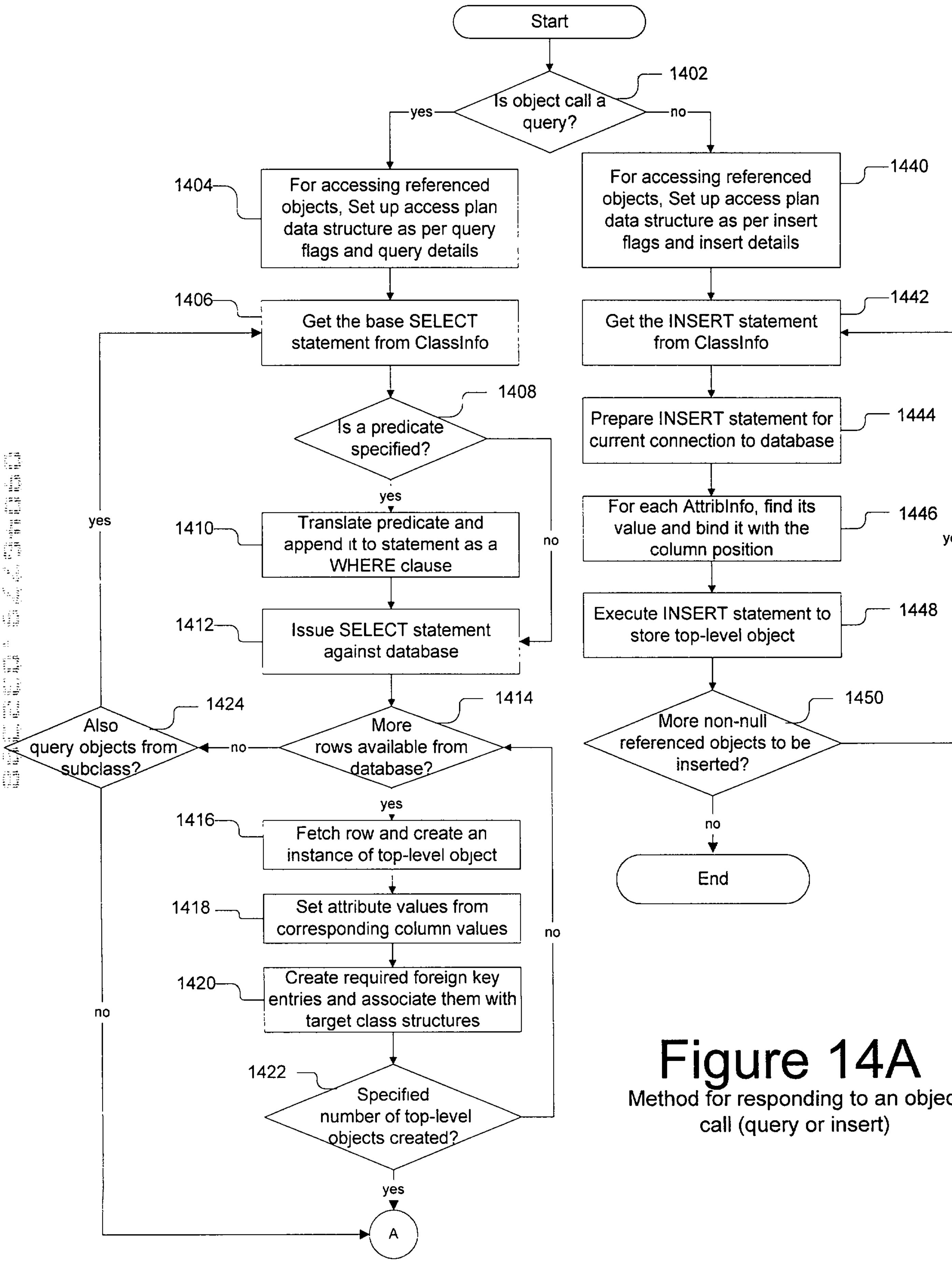


Figure 14A
Method for responding to an object call (query or insert)

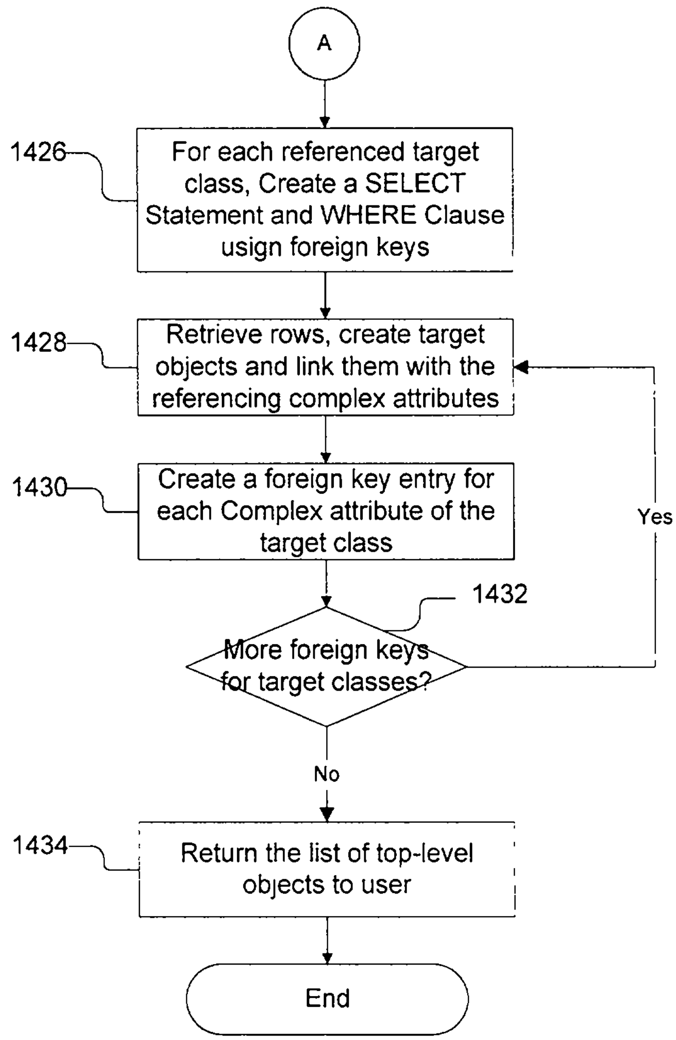

A
1426
For each referenced target class, Create a SELECT Statement and WHERE Clause usign foreign keys
1428
Retrieve rows, create target objects and link them with the referencing complex attributes
1430
Create a foreign key entry for each Complex attribute of the target class
1432
More foreign keys for target classes?
Yes
No
1434
Return the list of top-level objects to user
End

Figure 14B

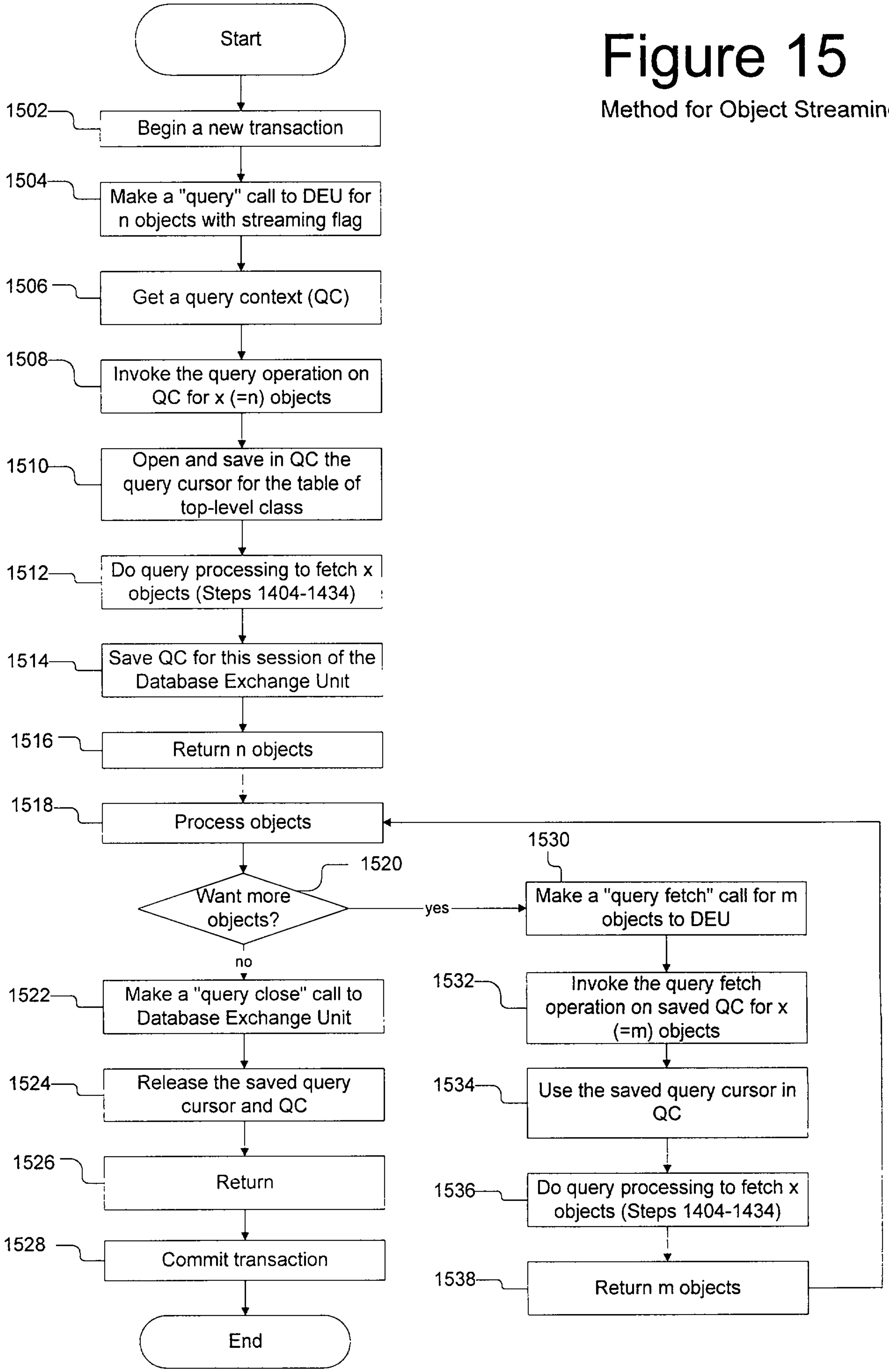


Figure 15

Method for Object Streaming

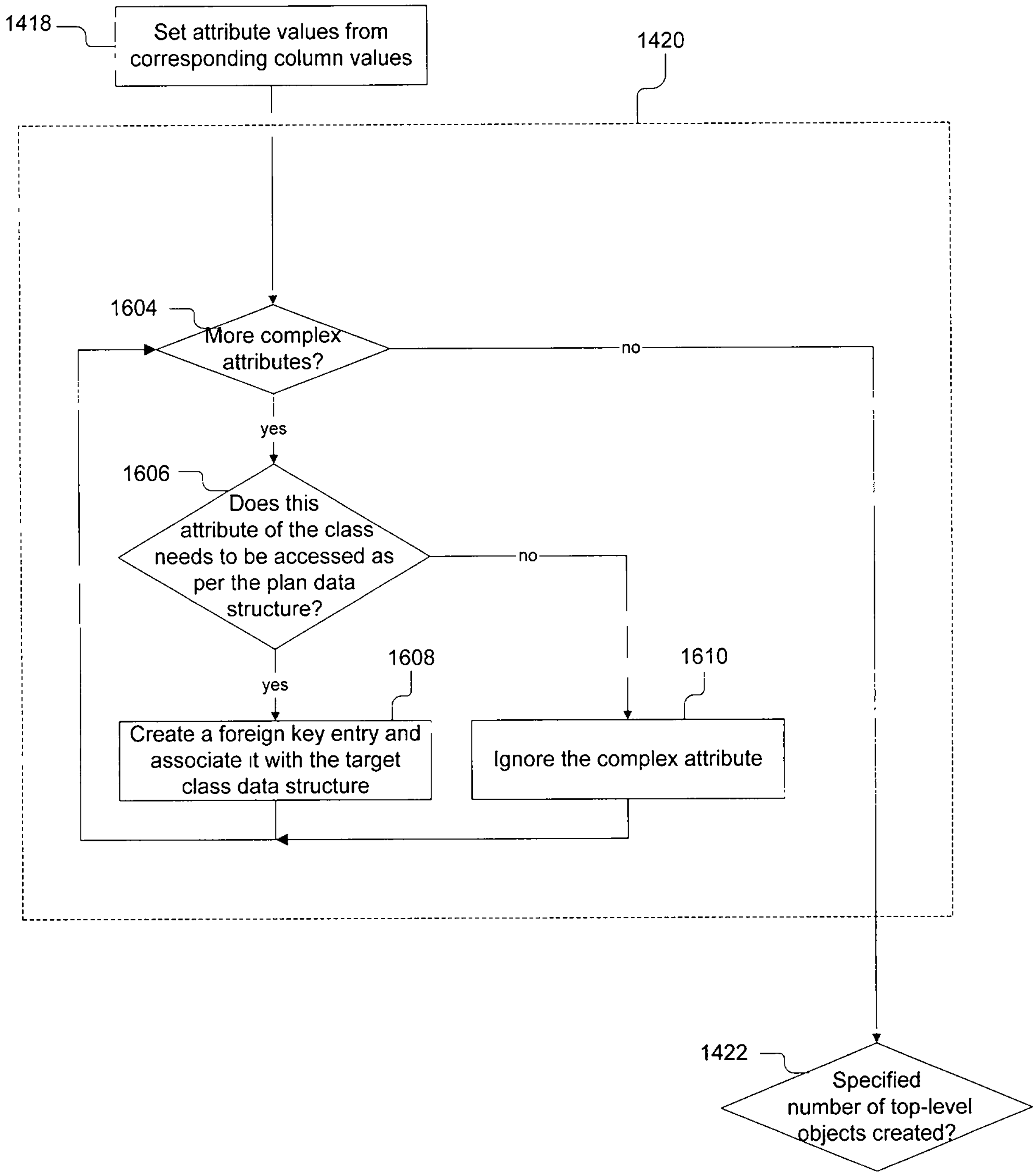


Figure 16

Method for Using Directed Operations for a Query Operation

```
<ORM-INFO>              ::= [;ORMId=<ORMId>] [;ORMFile=<fileName>]

<DATABASE-URL>          ::= <regularURL>[<ORM-INFO>]

<ENDDATABASE-SPEC>      ::= ;

<DATABASE-SPEC>         ::= DATABASE <DATABASE-URL>
                            <ENDDATABASE-SPEC>

<PRIMARY-KEY-SPEC>      ::= PRIMARY_KEY {<attribName> ...}

<REFERENCE-KEY-SPEC>    ::= REFERENCE_KEY <referenceKeyName>
                              {<attribName> ...}

<SQLMAP-SPEC>           ::= SQLMAP FOR <attribName>
                              [COLUMN_NAME <columnName>]
                              [SQLTYPE <sqlType>]
                              [NULLABLE]

<RELATIONSHIP-SPEC>     ::= RELATIONSHIP <attribName> REFERENCES <targetClassName>
                              {EMBEDDED | [BYVALUE] [REFERENCED_KEY
                              <referencedKeyName>] WITH <attribName> ...}

<ENDCLASS-SPEC>         ::= ;

<CLASS-SPEC>            ::= CLASS <className> [TABLE <tableName>]
                            <PRIMARY-KEY-SPEC>
                            [<REFERENCE-KEY-SPEC> ...]
                            [<SQLMAP> ...]
                            [<RELATIONSHIP-SPEC> ...]
                            <ENDCLASS-SPEC>

<ORDERBY-SPEC>          ::= ORDERBY {<attribName> ...}

<COLLECTION-CLASS-SPEC> ::= COLLECTION_CLASS <className>
                              COLLECTION_TYPE {ARRAY | VECTOR}
                              ELEMENT_CLASS <elelemtClassName>
                              [ELEMENT_TABLE <elementTableName>]
                            <PRIMARY-KEY-SPEC>
                            [<ORDERBY-SPEC>]
                            <ENDCLASS-SPEC>

<SEQUENCE-SPEC>         ::= SEQUENCE <sequenceName>
                              MAX_INCREMENT <maxIncrementValue>
                              [START_WITH <startingVal>]

<ORM-SPEC>              ::= <DATABASE-SPEC>
                          Any combination of <CLASS-SPEC>,
                              <COLLECTION-CLASS-SPEC>,
                              <SEQUENCE-SPEC> and <REMARK-SPEC>
```

FIGURE 17
ORM Grammar

```
DATABASE jdbc:odbc:sqlpubs;user=guest;password=hello;ORMId=pubs01
;
REM
CLASS RoySched TABLE roysched
PRIMARY_KEY title_id lorange
;
COLLECTION_CLASS ArrayRoySched COLLECTION_TYPE ARRAY
    ELEMENT_CLASS RoySched
PRIMARY_KEY title_id
ORDERBY royalty
;
CLASS Title TABLE titles
PRIMARY_KEY title_id
RELATIONSHIP royscheds REFERENCES ArrayRoySched BYVALUE WITH
    title_id
SQLMAP FOR price SQLTYPE Money
;
COLLECTION_CLASS ArrayTitle COLLECTION_TYPE ARRAY ELEMENT_CLASS
    Title
PRIMARY_KEY pub_id
ORDERBY ytd_sales title_id
;
CLASS PubInfo TABLE pub_info
PRIMARY_KEY pub_id
SQLMAP FOR logo SQLTYPE image
SQLMAP FOR prInfo COLUMN_NAME pr_info SQLTYPE text
;
CLASS Publisher TABLE publishers
PRIMARY_KEY pub_id
RELATIONSHIP pubInfo REFERENCES PubInfo BYVALUE  WITH pub_id
RELATIONSHIP titles REFERENCES ArrayTitle BYVALUE WITH pub_id
;
CLASS Job TABLE jobs
PRIMARY_KEY job_id
;
CLASS Emp TABLE employee
PRIMARY_KEY emp_id
RELATIONSHIP job REFERENCES Job REFERENCED_KEY PrimaryKey WITH
    job_id
RELATIONSHIP publisher REFERENCES Publisher WITH pub_id
;
CLASS TitlePub
PRIMARY_KEY title_id
;
CLASS LinkList TABLE linklist
PRIMARY_KEY link_id
RELATIONSHIP next REFERENCES LinkList BYVALUE WITH next_link_id
;
```

FIGURE 18

ORM Specification

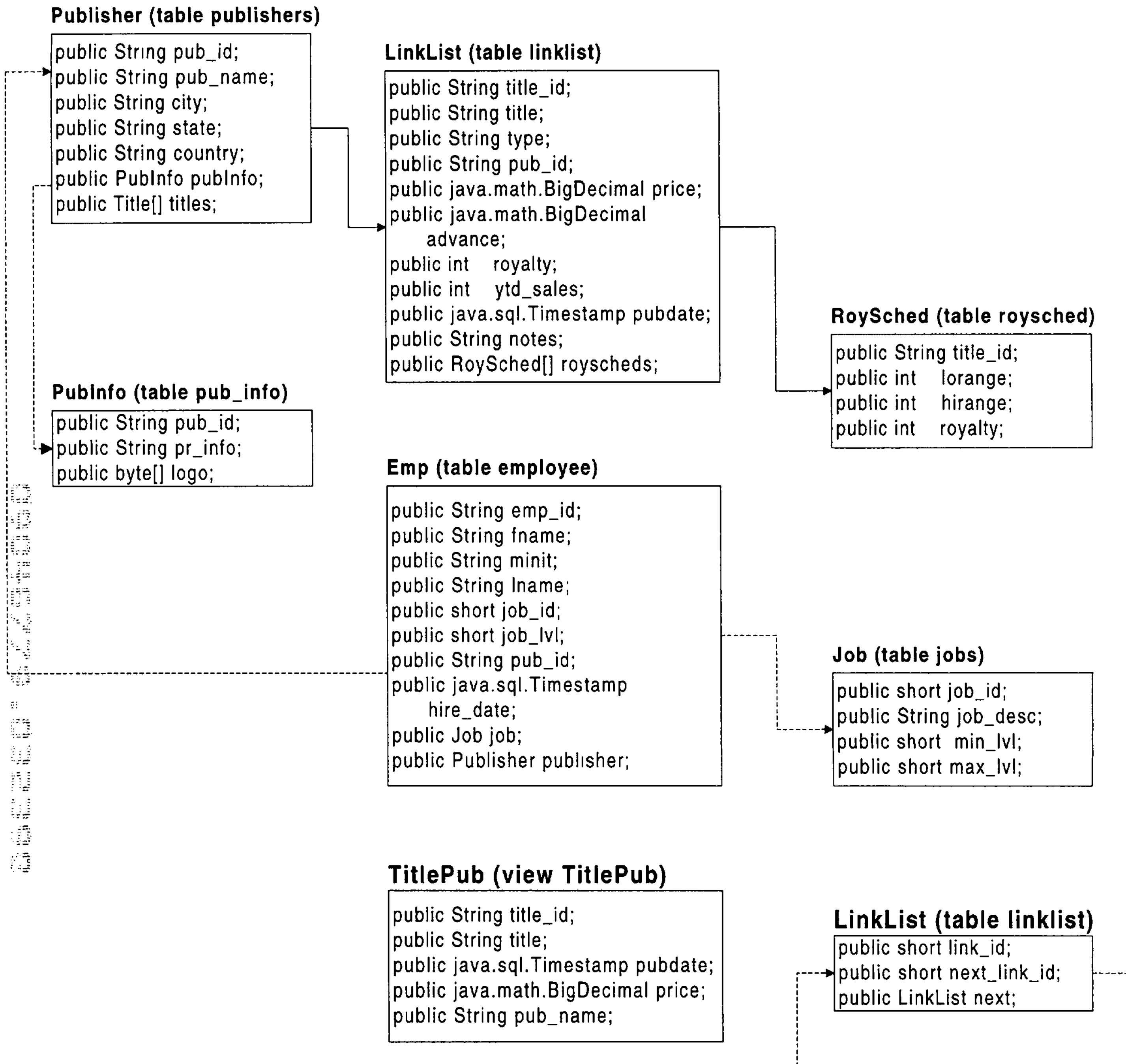


Figure 19

ORM Spec Graphical rep

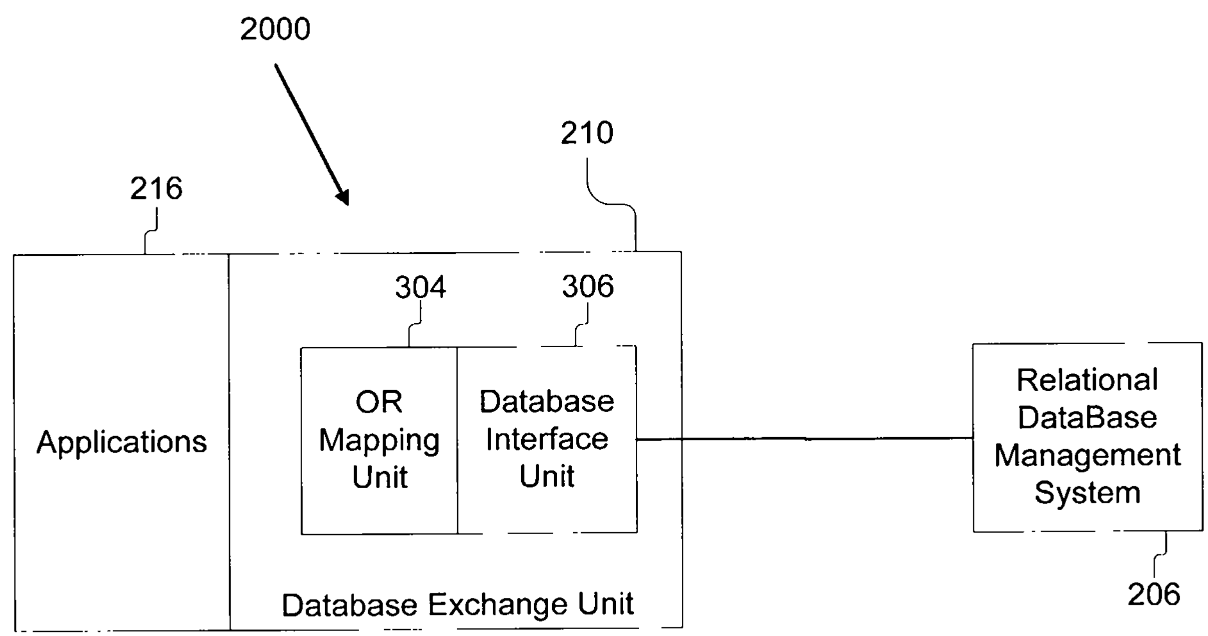

2000
210
216
304
306
Applications
OR Mapping Unit
Database Interface Unit
Database Exchange Unit
Relational DataBase Management System
206

Figure 20A

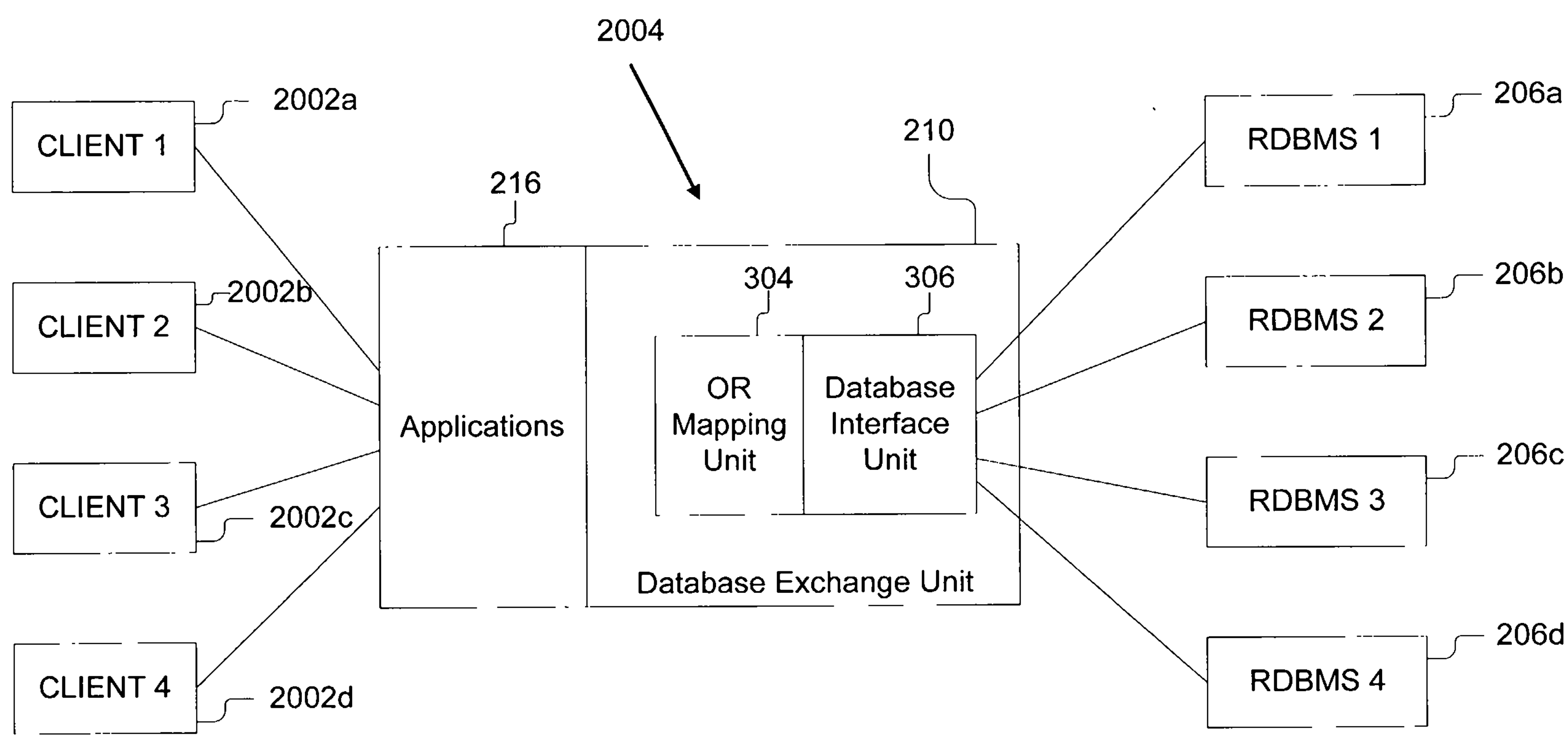

2004
CLIENT 1
2002a
CLIENT 2
2002b
CLIENT 3
2002c
CLIENT 4
2002d
216
Applications
210
304
306
OR Mapping Unit
Database Interface Unit
Database Exchange Unit
RDBMS 1
206a
RDBMS 2
206b
RDBMS 3
206c
RDBMS 4
206d

Figure 20B

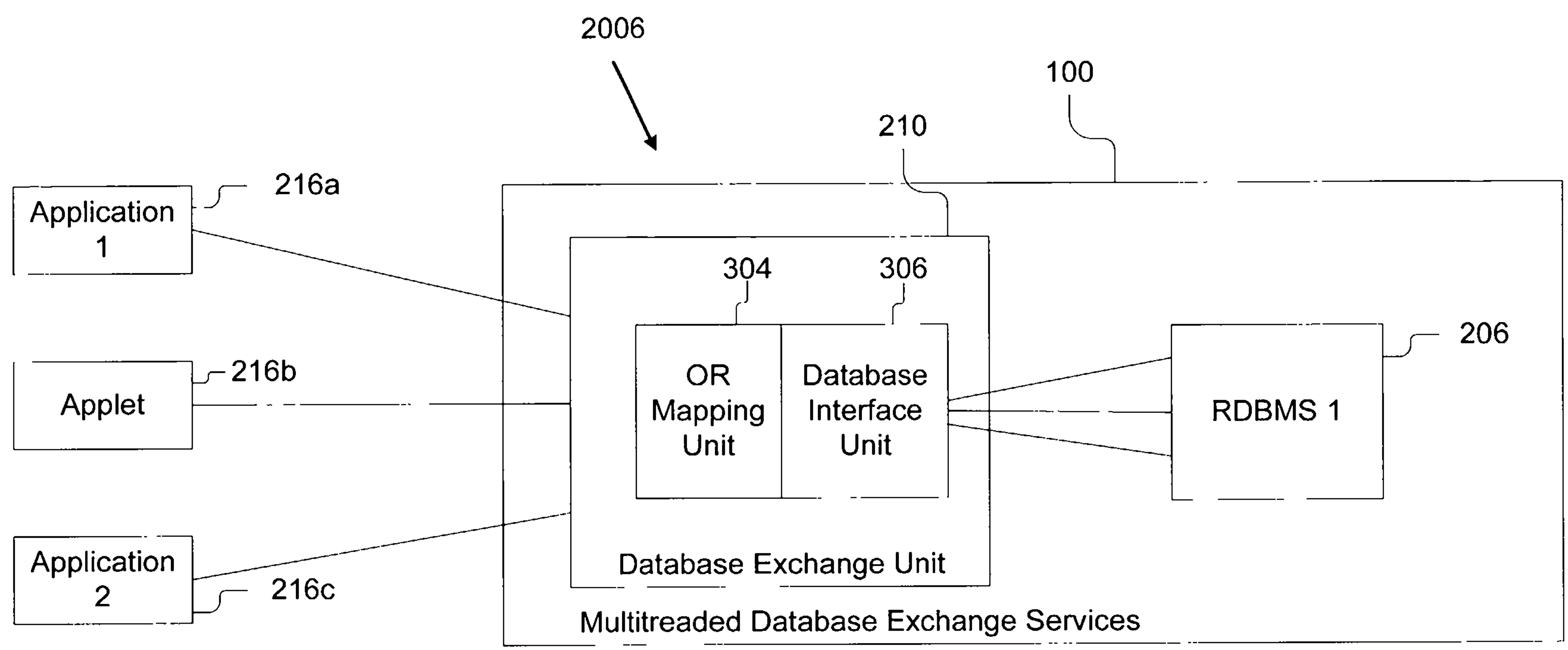
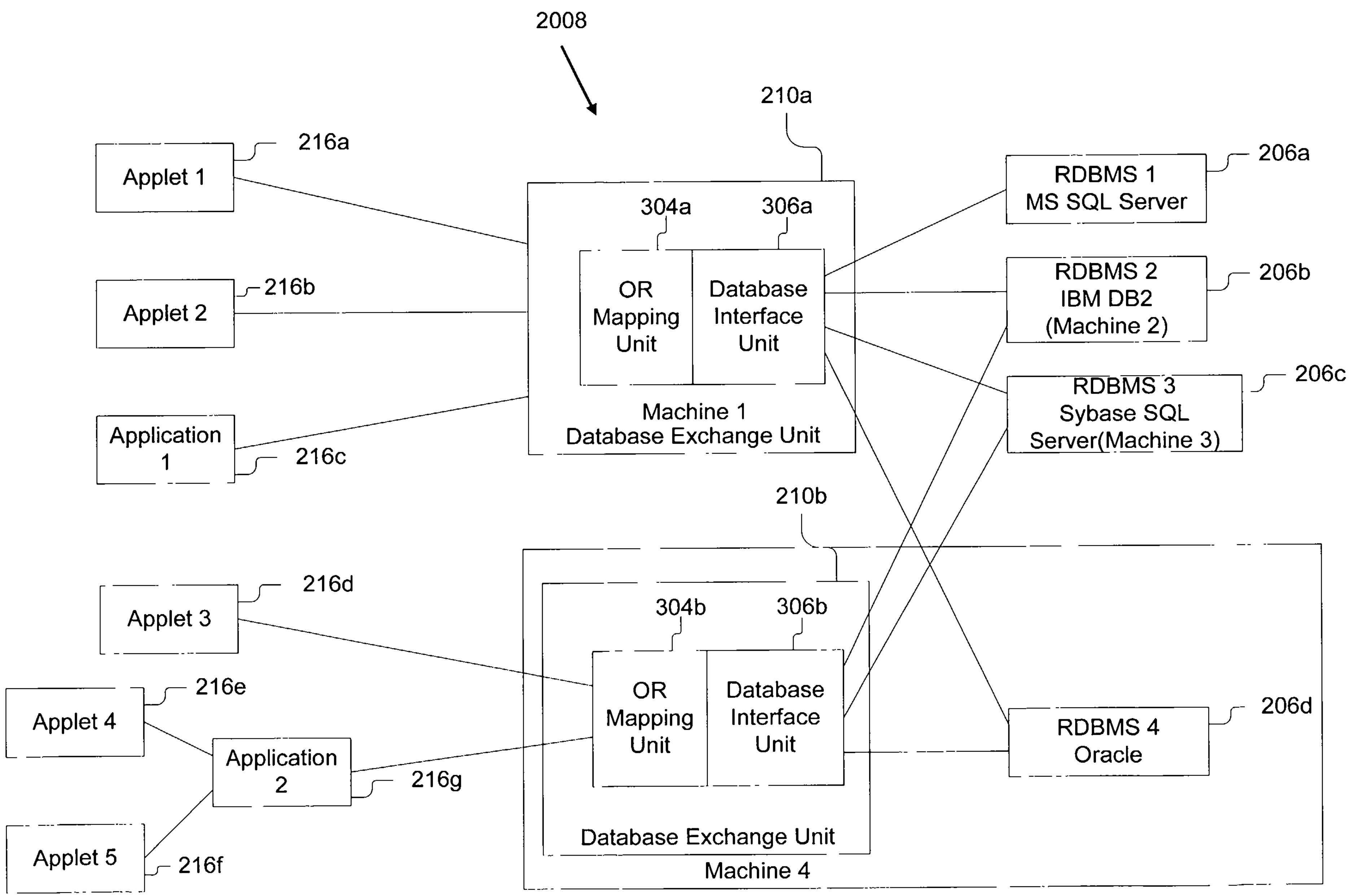

2006
100
210
216a
Application
1
304
306
206
216b
Applet
OR
Mapping
Unit
Database
Interface
Unit
RDBMS 1
Application
2
216c
Database Exchange Unit
Multitreaded Database Exchange Services

Figure 20C



2008
210a
216a
Applet 1
216b
Applet 2
Application
1
216c
304a
306a
OR
Mapping
Unit
Database
Interface
Unit
Machine 1
Database Exchange Unit
206a
RDBMS 1
MS SQL Server
206b
RDBMS 2
IBM DB2
(Machine 2)
206c
RDBMS 3
Sybase SQL
Server(Machine 3)
210b
216d
Applet 3
216e
Applet 4
Application
2
216g
Applet 5
216f
304b
306b
OR
Mapping
Unit
Database
Interface
Unit
Database Exchange Unit
Machine 4
206d
RDBMS 4
Oracle

Figure 20D

FIGURE 21A

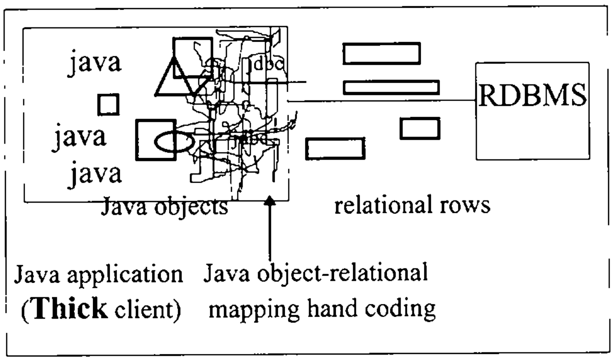
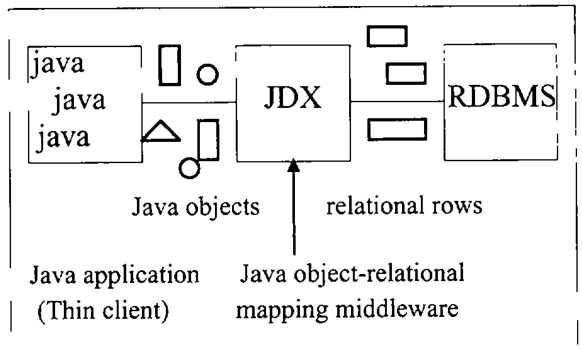


FIGURE 21B



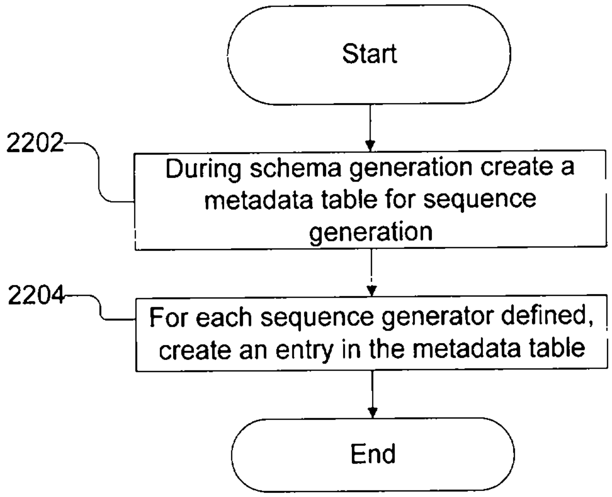


Figure 22A

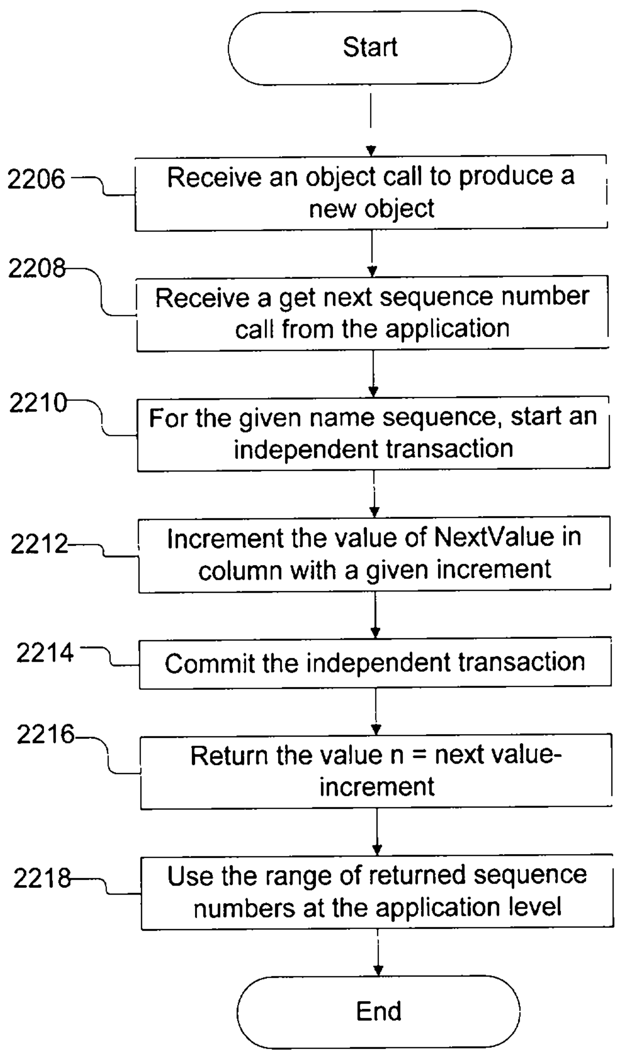


Figure 22B

Method for Generating and using Named Sequence Generators

0010/PTO
Rev. 6/95

U.S. Department of Commerce
Patent and Trademark Office

DECLARATION FOR UTILITY OR DESIGN PATENT APPLICATION

[X] Declaration Submitted with Initial Filing OR [ ] Declaration Submitted after Initial Filing

Attorney Docket Number	**2962**
First Named Inventor	**Damodar Das Periwal**
COMPLETE IF KNOWN	
Application Number	
Filing Date	
Group Art Unit	
Examiner Name	

As a below named inventor, I hereby declare that:

My residence, post office address, and citizenship are as stated below next to my name.

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled:

A SYSTEM AND METHOD FOR EXCHANGING DATA AND COMMANDS BETWEEN AN OBJECT ORIENTED SYSTEM AND A RELATIONAL SYSTEM

the specification of which (*Title of the Invention*)

[X] is attached hereto

OR

[ ] was filed on (MM/DD/YYYY) [ ] as United States Application Number or PCT International Application Number [ ] and was amended on (MM/DD/YYYY) [ ] (if applicable).

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment specifically referred to above.

I acknowledge the duty to disclose information which is material to patentability as defined in Title 37 Code of Federal Regulations § 1.56.

I hereby claim foreign priority benefits under Title 35, United States Code § 119 (a)-(d) or § 385(b) of any foreign application(s) for patent or inventor's certificate, or § 365 (a) of any PCT international application which designated at least one country other than the United States of America, listed below and have also identified below, by checking the box, any foreign application for patent or inventor's certificate, or of any PCT international application having a filing date before that of the application on which priority is claimed

Prior Foreign Application Number(s)	Country	Foreign Filing Date (MM/DD/YYYY)	Priority Not Claimed	Certified Copy Attached? YES	NO
			[ ]	[ ]	[ ]
			[ ]	[ ]	[ ]
			[ ]	[ ]	[ ]
			[ ]	[ ]	[ ]
			[ ]	[ ]	[ ]

[ ] Additional foreign application numbers are listed on a supplemental priority sheet attached hereto:

I hereby claim the benefit under Title 35, United States Code § 119(e) of any United States provisional application(s) listed below.

Application Number(s)	Filing Date (MM/DD/YYYY)	
60/051,108	**06/26/1997**	[ ] Additional provisional application numbers are listed on a supplemental sheet attached hereto.

DECLARATION	Page 2

I hereby claim the benefit under Title 35, United States Code § 120 of any United States application(s), or § 365(c) of any PCT international application designating the United States of America, listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States or PCT international application in the manner provided by the first paragraph of Title 35, United States Code § 112, I acknowledge the duty to disclose information which is material to patentability as defined in Title 37, Code of Federal Regulations § 1.56 which became available between the filing date of the prior application and the national or PCT international filing date of this application.

U.S. Parent Application Number	PCT Parent Number	Parent Filing Date (MM/DD/YYYY)	Parent Patent Number (*if applicable*)

[ ] Additional U.S. or PCT international application numbers are listed on a supplemental priority sheet attached hereto.

As a named inventor, I hereby appoint the following attorney(s) and/or agent(s) to prosecute this application and to transact all business in the Patent and Trademark Office connected therewith:

Name	Registration Number	Name	Registration Number
Greg T. Sueoka	**33,800**		

[ ] Additional attorney(s) and/or agent(s) named on a supplemental sheet attached hereto.

Please direct all correspondence to:

Greg T. Sueoka
Fenwick & West LLP
Two Palo Alto Square
Palo Alto, CA 94306
U.S.A.

Telephone	**(650) 858-7194**	Fax	**(650) 494-1417**

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

Name of Sole or First Inventor: [ ] A petition has been filed for this unsigned inventor

Given Name	**Damodar**	Middle Initial	**D.**	Family Name	**Periwal**	Suffix e.g. Jr.	

Inventor's Signature	Damodar Das Periwal	Date	3-22-1998

Residence: City	**Campbell**	State	**CA**	Country	**95008**	Citizenship	**USA**
Mailing Address	**1274 Colleen Way**						
Mailing Address							
City	**Campbell**	State	**CA**	Zip	**95008**	Country	**USA**

[ ] Additional inventors are being named on supplemental sheet(s) attached hereto

PTO/SB/ 10 (6-95) (modified)
Approved for use through 07/31/96. OMB 0651-0031
Patent and Trademark Office: U.S. DEPARTMENT OF COMMERCE

VERIFIED STATEMENT CLAIMING SMALL ENTITY STATUS (37 CFR 1.9(f) & 1.27(c))--SMALL BUSINESS CONCERN	Docket Number (Optional): 2962

Applicant or Patentee: Damodar Das Periwal

Application or Patent No.: ______

Filing Date or Issue Date: ______

Title: A System and Method for Exchanging Data and Commands Between an Object Oriented System and a Relational System

I hereby declare that I am

[ ] the owner of the small business concern identified below:

[X] an official of the small business concern empowered to act on behalf of the concern identified below:

NAME OF SMALL BUSINESS CONCERN Software Tree, Inc.

ADDRESS OF SMALL BUSINESS CONCERN 650 Saratoga Avenue
San Jose, CA 95129

I hereby declare that the above identified small business concern qualifies as a small business concern as defined in 13 CFR 121.12, and reproduced in 37 CFR 1.9(d), for purposes of paying reduced fees to the United States Patent and Trademark Office, in that the number of employees of the concern, including those of its affiliates, does not exceed 500 persons. For purposes of this statement, (1) the number of employees of the business concern is the average over the previous fiscal year of the concern of the persons employed on a full-time, part-time or temporary basis during each of the pay periods of the fiscal year, and (2) concerns are affiliates of each other when either, directly or indirectly, one concern controls or has the power to control the other, or a third party or parties controls or has the power to control both.

I hereby declare that rights under contract or law have been conveyed to and remain with the small business concern identified above with regard to the invention described in:

[X] the specification filed herewith with title as listed above.

[ ] the application identified above.

[ ] the patent identified above.

If the rights held by the above identified small business concern are not exclusive, each individual, concern or organization having rights in the invention must file separate verified statements averring to their status as small entities, and no rights to the invention are held by any person, other than the inventor, who would not qualify as an independent inventor under 37CFR 1.9(c) if that person made the invention, or by any concern which would not qualify as a small business concern under 37 CFR 1.9(d), or a nonprofit organization under 37 CFR 1.9(e).

Each such person, concern or organization having any rights in the invention is listed below:

[X] No such person, concern, or organization exists.

[ ] Each such person, concern or organization is listed below:

______

______

Separate verified statements are required from each named person, concern or organization having rights to the invention averring to their status as small entities. (37 CFR 1.27)

I acknowledge the duty to file, in this application or patent, notification of any change in status resulting in loss of entitlement to small entity status prior to paying, or at the time of paying, the earliest of the issue fee or any maintenance fee due after the date on which status as a small entity is no longer appropriate. (37 CFR 1.28(b))

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application, any patent issuing thereon, or any patent to which this verified statement is directed.

NAME OF PERSON SIGNING Damodar Das Periwal

TITLE OF PERSON IF OTHER THAN OWNER President

ADDRESS OF PERSON SIGNING 650 Saratoga Avenue, San Jose, California 95129

SIGNATURE Damodar Das Periwal DATE 3-22-1998